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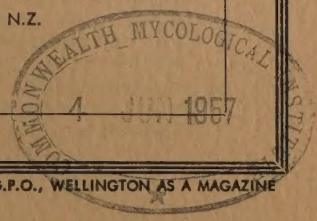

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Journal of Science and Technology

VOLUME 38, No. 6, 1957

(AGRICULTURAL RESEARCH SECTION)

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NOTICES

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NOTICE

Volume 38 of the *New Zealand Journal of Science and Technology* will be continued to the end of 1957, instead of concluding in April (Section A) and May (Section B).

Current subscriptions cover the additional issues of both Sections to the end of the year.

This is the final volume under the present title.

In January 1958, *N.Z. J. Sci. Tech.* will be replaced by three separate journals, viz.:

New Zealand Journal of Agricultural Research

New Zealand Journal of Geology and Geophysics

New Zealand Journal of Science.

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A SUCTION-OPERATED PRECISION SEEDER

By I. C. SWEETMAN, Rukuhia Soil Research Station, Hamilton

(*Received for publication, 26 November 1956*)

Summary

A precision seeder is described, which has been devised for sowing small seeds singly, at adjustable spacing by means of suction applied to fine-bore tubes.

INTRODUCTION

In trials laid down by the Weed Control Section, Rukuhia Soil Research Station, to determine the tolerance of clover plants to various weedkillers, it was necessary to sow a considerable area with white, red, and subterranean clover in rows, singly, at two-inch spacing between seeds. Sowing of single seeds, accurately spaced, was of prime importance (Thompson, 1956).

For this purpose, a prototype precision seeder was constructed to select and sow single seeds by means of suction applied to lengths of hypodermic-needle tubing. The seeder was used with satisfactory results.

DESCRIPTION OF VACUUM SEEDER

Selector Disc

A perspex disc, 2 in. in diameter and $1\frac{1}{4}$ in. thick was drilled, and the hole, $\frac{13}{16}$ in. diameter by $\frac{13}{16}$ in. deep, was fitted with a steel liner (H, Fig. 1) to receive the suction boss (A, Fig. 1).

The circumference of this disc was divided into twelve and drilled to provide twelve radial suction channels, which were counterbored $\frac{1}{4}$ in. diameter to $\frac{3}{8}$ in. depth to receive rubber plugs (E, Fig. 1). Hypodermic needles of appropriate gauge, and $1\frac{1}{2}$ in. in length, were pushed through the rubber plugs until 1 in. remained protruding externally. The disc was then attached to the star wheel of a suitably modified Planet Junior seeder.

Suction Boss

The suction boss was turned from a length of $1\frac{1}{4}$ in. diameter "tufol" rod, with a groove or circular channell $\frac{1}{8}$ in. wide by $\frac{1}{8}$ in. deep (X, Fig. 2) designed to coincide with the radial holes already drilled

in the selector disc and liner. This groove was connected with the vacuum spigot (C, Fig. 1) by a short sloping hole opening into a $\frac{1}{4}$-in. diameter hole drilled down the spigot centre, and served as a channel supplying vacuum to the needles mounted in the revolving selector disc.

To permit seed release, a vacuum-release system was added to the circular vacuum channel. A vent hole (B, Fig. 1) was drilled to emerge in the channel diametrically opposite to the point of entry of the vacuum hole (X, Fig. 2) and the channel plugged on each side of the vent with $\frac{3}{16}$-in. diameter tufnol pins thus providing a section approximately $\frac{1}{4}$-in. in length, sealed off from vacuum but open to atmospheric pressure (Y, Fig. 2). A thin smear of grease provided a vacuum-tight joint between the stationary central boss and the revolving selector disc.

Seed Hopper

A seed hopper of approximately 100 cc. capacity with a $\frac{1}{2}$-in. diameter copper discharge tube attached, was fitted below the disc and positioned so that the seeds, picked up singly by the vacuum at the needle orifices, were carried through an arc of not less than 180° and thrown down the discharge tube when the vacuum was broken by the release system described.

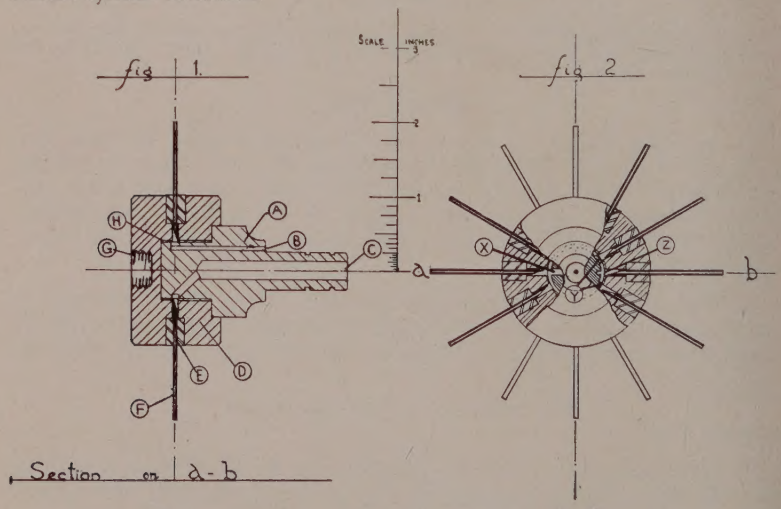

Fig. 1 Fig. 2

Fig. 1.—Cross section of rotating disc showing details of vacuum channel and vent.

A. Suction boss.
B. Vent for releasing vacuum.
C. Vacuum spigot
D. Rotating disc
E. Rubber plug.
F. Hypodermic needle
G. Thread for attachment to driving pinion or sprocket.
H. Steel liner in rotating disc.

Fig. 2.—Side elevation of rotating disc with suction boss in position. Cutaway portion.

X. Vacuum channel.
Y. Blocking pieces.
Z. Vented portion of channel.

Operation of Vacuum Seeder

For sowing operations, the Planet Junior seeder with vacuum sowing unit incorporated was mounted on the mid-positioned tool bar

of an Allis-Chalmers "G" tractor. Enough suction (15 in. mercury) was obtained from the tractor induction manifold for sowing the white and the red clover. For the subterranean clover, a small laboratory vacuum pump (Edwards R.B. 1) driven from the power take-off at a speed sufficient to maintain a vacuum-gauge reading of 17–20 in. of mercury was necessary, because the induction manifold vacuum was too weak and unstable for the large seeds.

This single unit was mounted outside the wheel track and each area was sown starting with the centre rows to avoid spoiling sown drills with the tractor wheels. Spring mounting assured firm ground contact of the implement drive wheel over slightly uneven surfaces and the sown drill was covered by means of adjustable side blades on the coulter and a concave press wheel.

The hypodermic needle sizes found suitable with a vacuum-gauge reading of 17 to 20 in. of mercury were:

White clover	23 gauge
Red clover	21 gauge
Subterranean clover	18 gauge

The Tallarook subterranean clover used in the trial was specially selected for high purity and germination, and was approximately twice the size of normal commercial lines.

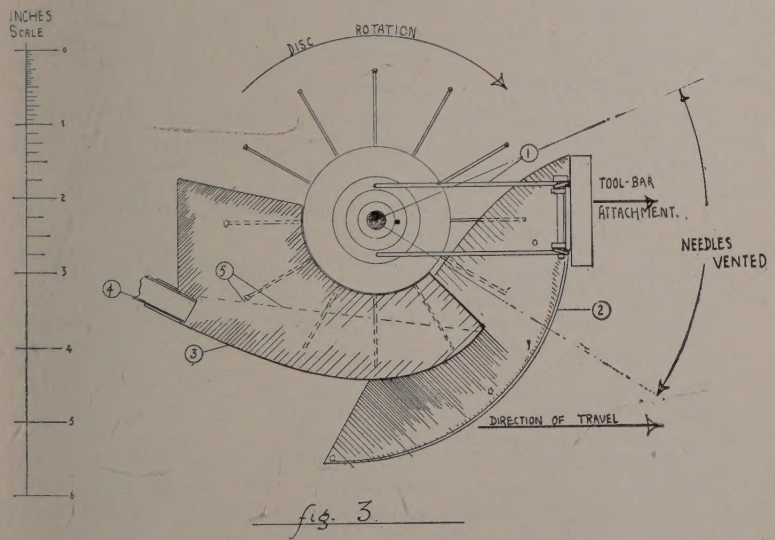

Fig. 3.—Side elevation showing low-capacity seed hopper and coulter/discharge tube in position.

(1) Spring-wire 2-pronged clip locating suction boss.
(2) Hollow V-section coulter/discharge tube.
(3) Hopper (low capacity).
(4) Flexible plastic tube connection from reserve hopper.
(5) Average level of seed in hopper while sowing (Adjustable by (4)).

The drive wheel of the Planet Junior seeder measured 3 ft. in circumference, so that, with a 3 to 2 gear ratio, the division of the selector

disc into twelve gave 2-in. spacing between seeds. Accuracy of spacing was little affected by the length of the discharge tube because this was short, but the angle of discharge resulted in occasional displacement of seed in the drill. Owing to this defect, an alteration in design was made by combining the discharge tube and coulter (2, Fig. 3). The improved coulter was made from two segments of a circle welded together along one edge to form a curved, V-shaped channel with the bottom of the groove filled with metal and ground to a smooth curve to permit unobstructed passage of the seed.

At the start of each sowing run, the tool bar was lowered until the driving wheel had firm contact, and the coulter was at the correct sowing depth. Forward motion then passed the needles through the seed hopper, each needle picking up a seed which was carried round until the vacuum was released and the seed discharged into the drill.

The hopper was constructed with perspex sides, so that the residual quantity of seed was visible to the operator who could also readily observe whether the needles were picking up the seeds (Fig. 3).

DISCUSSION

Experimentation with different methods of mounting the implement and covering the drill was considered unnecessary as these accessory requirements appear to be well established in the field of precision seeding equipment.

Apart from the above, the most important requirements for precision seeding equipment are:

(1) The sowing mechanism should not damage the seed.

(2) The selector mechanism should invariably pick up a single seed on each point.

(3) The seeder should be readily adaptable to different seed varieties and rates of sowing (spacing).

(4) The spacing accuracy should be preserved in the drill at varying speeds.

(5) The depth of sowing should be even and readily adjustable.

(6) The operator must be able to see if any unit is not operating.

The extent to which the vacuum seeder meets these requirements, depends in some instances on operating factors which will be explained.

(*1*) *Seed damage.* With the vacuum seeder, this is eliminated.

(*2*) *Accuracy of pick-up.* In preliminary tests with vacuum, it was found that two or more seeds were sometimes picked up by the one orifice. The following factors were found to influence the accuracy of performance.

(a) Size of needle orifice.

(b) Degree and steadiness of vacuum applied.

(c) Size and weight of seed in relation to (a) and (b).

(d) Speed of the needle orifice moving through loose seed in the hopper, and any tendency of the seed variety to "pack" in a small hopper (e.g. parsnip, beet).

This means that, for 100% accuracy, the orifice size, the vacuum, and the speed through the hopper must be balanced so that each orifice collects one seed and holds it until the vacuum is released.

If reducing the vacuum does not correct any tendency to multiple pick up, it is necessary to change to a smaller needle size. This operation can be speeded up by fitting the selector disc with tapered push-fit mounts, but the most satisfactory method of changing needle size or spacing would be the provision of interchangeable selector discs with rubber mounts.

(3) *Adaptability to variety of seed and spacing.* The vacuum seeder is particularly suitable and adaptable for small seed and seed of irregular shape. Several different varieties can be sown with one needle size by regulating the vacuum. Bench tests showed satisfactory performance with lettuce, carrot, parsnip, and wheat, and, with a wider hopper, "cluster" seeds such as beet should be handled satisfactorily. The tendency for seed such as beet and parsnip to pack in a hopper impairs the pick-up efficiency, particularly if the speed of travel is relatively high.

Alterations to sowing rate (spacing) can be achieved by a change of gear ratio in the drive mechanism, by the removal or sealing-off of intermediate needles, or by changing over to a selector disc fitted with a different number of needles. If needles are removed to give increased spacing, the self-sealing nature of the rubber mounts is convenient.

(4) *Accuracy of spacing in the drill.* With precision seeders, accuracy of spacing is often spoilt by intermittent delays in seed travel through comparatively long discharge tubes and also by displacement in the drill caused by the angle of discharge and forward speed of the sowing assembly. The vacuum seeder provides an accurate method of picking up single seeds at reasonable speed, and gearing can be arranged so that the velocity of the seed at the release point is comparable with the forward speed of the sowing assembly, and, with the seed directed backwards, displacement is thus minimised.

(5) *Depth of sowing.* The small dimensions of the vacuum seeder are of assistance in designing a complete assembly, as the drive wheel and press wheel can be set close together. This, together with independent spring mounting for each unit, assists adjustment and maintenance of even sowing depth on uneven ground.

(6) *Visibility to operator.* Transparent sides for seed hoppers, and exposure to view of the upper half of the selector disc, enable the operator to keep a visual check on the hopper contents and the efficiency of pick up. It is possible to block the discharge tube if the tractor moves backward with the unit in the lowered position. Such blockages, although rare, are difficult to detect immediately and must be avoided.

SPECIAL REQUIREMENTS OF VACUUM SEEDER

(1) *Cleanliness of seed.* Cleaned seed is advisable. If needle blockages occur through accidental contamination of the seed, it may be possible to keep the needles clear by coupling a small air blast to the vacuum release vent.

(2) *Vacuum pump.* A small milking-machine pump would probably be suitable for multiple units handling a wide range of seed varieties.

(3) *Protection from air-borne grit.* This is necessary for most precision seeders but with vacuum present, any grit adhering to joints holding vacuum is readily sucked in, resulting in rapid wear of moving parts. Fortunately there is only one such joint in the seeder described, and an efficient dust seal can be designed.

Disadvantages

A disadvantage with the vacuum seeder is that it cannot be manually operated as a unit independent of the tractor because of the vacuum requirement.

Suggested Improvements

(1) Sufficient units to cover the width of the tractor should be employed.

(2) Spring mountings for both drive wheel and press wheel are recommended.

(3) For large operations, especially with large seed, a reserve hopper is required, and a flexible plastic tube connection (4, Fig. 3), working as an adjustable constant-level feed, is recommended.

(4) The materials used in the prototype components are giving good service with limited use but adequate testing may possibly reveal the need for harder-wearing materials.

(5) Spare selector discs with varying needle size and spacing are recommended.

(6) If, for reasons of poor germination, it is necessary to sow clusters of 2 or 3 seeds at once, this can be accomplished by an alteration in the shape of the needle orifice.

(7) Provision of a conveniently placed regulator on the vacuum line or pump is recommended. A vacuum reserve tank of one or two gallons capacity would enable a pump of insufficient capacity to cope with intermittent vacuum leaks.

(8) Recent observations have shown the advantages of using a much lower degree of vacuum (5 in. mercury or less) than that originally employed (15 to 20 in. mercury). Slightly larger needle sizes are required, but intermittent leaks are kept to a minimum and a separate vacuum pump may be unnecessary.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the assistance of Mr. D. F. Waters for suggesting the use of vacuum, and Mr. F. B. Thompson and staff of the Weed Control Section for their interest and perseverance with a new technique and experimental model.

REFERENCE

1. THOMPSON, F. B. 1956: Clover Tolerance. *Proc. 9th N.Z. Weed Conf.*

WEAR IN SHEEP'S TEETH

By C. R. Barnicoat, Massey Agricultural College, Palmerston North

Summary and Conclusions

The quality of mouths of sheep in New Zealand, particularly in certain parts of the North Island, has progressively deteriorated during the last 30 or 40 years. The problem, which is of considerable economic importance, has been investigated for several years at this College. This article describes results of field and nutritional experiments on sheep of the New Zealand Romney breed made concurrently with laboratory studies which are still in progress.

The problem is concerned with the excessive wear of the incisors resulting from abrasion, and probably also erosion, and is not due to caries (decay). No differences have so far been detected in the chemical composition or in the finer structure of teeth from various sources or with different amounts of wear.

The rates of wear of teeth of grazing sheep are governed chiefly by (a) inherent and congenital differences between mouths of individuals, and (b) external factors, particularly those affecting the nature of the food. The latter are primarily concerned in this problem since the progressive deterioration in quality of teeth of grazing sheep is associated with their increased consumption of herbage from pastures of the high-yielding European type.

The incisor teeth normally emerge from the gum slowly as the sheep matures, but excessive wear exposes the pulps and causes the teeth to erupt more rapidly. Mouths with initially large, wide teeth will tend to last well. There are, however, various defects which are conducive to wear, the undershot (short lower) jaw being the most common. The great differences in rates of wear and in the ages at which teeth are cut render it difficult nowadays to estimate the ages of sheep by means of the traditional practice of "mouthing".

External influences—environmental, managemental, and nutritional—can modify considerably the abrasive action of herbage. Climatic factors, though indirect, are important. Broad correlations are found between tooth quality and soil type, but no clear connection with known trace-element deficiencies. Managemental factors are also important since overgrazing on all types of country promotes rapid wear. On the other hand, the practice of "controlled rotational grazing" on improved hill-country sheep farms has proved advantageous, since the ewes retained good mouths. Grazing practices have subtle but important influences on the rate of wear of sheep's teeth.

Although chemical investigations have not shown the problem to be a nutritional one in the generally accepted sense, it has been found that certain substances in rapidly growing herbage, such as compounds of certain organic acids, can dissolve the hard calcium phosphate from teeth and probably contribute to wear by the process of erosion.

While the pasture appears to have the dominating influence on wear, individual animals vary considerably through hereditary and congenital (i.e. initial) differences in size and conformation of their teeth and jaws. Improvement in the average quality of mouths in a flock would be most rapidly achieved by eliminating ewes and rams with undesirable mouths. In order to facilitate this selection, the courses of development of the principal faults in sheep's mouths have been classified and illustrated.

The investigation, both in the field and the laboratory, is proceeding.

Part 1. Introduction

Under New Zealand conditions of sheepfarming, ewes are bred on the hill country and sold usually when 5½ years* old for "fat-lamb" production on specialized farms in the lower fertile country. In the North Island such cast-for-age ewes are almost exclusively Romneys.

Since the thrift and productivity of ewes are primarily dependent on an adequate intake of nutrients, considerable emphasis is laid by both sheep breeders and fat-lamb farmers on the soundness of the ewes' mouths. Breeders cull, at as early a stage as possible, animals with mouth deformities or irregularities in dentition, and, at a later stage, animals with mouths showing undue wear. Fat-lamb farmers critically examine mouths of aged ewes before purchasing.

It is frequently stated by farmers that excessive wear in sheep's teeth has been evident in certain parts of New Zealand since the early stages of the industry, but it is clear that the problem has become aggravated during the last 30 or 40 years, particularly on the better-class hill country of the North Island used for breeding purposes. As a result, it is sometimes necessary to cull ewes at 4 instead of 5 (or even 6) years of age, a most undesirable practice because:—

(a) The overhead cost of maintaining the flock is increased when the ewe is sold at 4 instead of 5 years of age, with only 3 instead of 4 profitable lambing seasons.

(b) Ewes culled at an early stage for defective mouths might possess otherwise desirable characteristics which would normally guarantee their retention in the flock. Moreover, they are removed before they have attained their highest fertility (Barton, 1947).

(c) If culling at 4 years is heavy, breeders may be forced to buy replacements for their flocks, and animals that would normally be culled at the 2-tooth stage are retained to keep up the flock numbers.

(d) Ewes with poor mouths may not be accepted by the buyers as true-to-age in districts where age-marking is not carried out. Even where age-marking is practised (i.e. most of the North Island) ewes with failing mouths command lower prices than sound-mouthed sheep of the same age. For example, in one particular district during a recent season, 5-year-old breeding ewes with sound mouths ("2-year fat-lamb" ewes) were sold for 50/-, similar ewes with "1-year" mouths for 42/6d (15% less), while "gummies" were bought by the freezing works for 30/-, 40% less than the sound-mouthed sheep.

The rejection of otherwise useful breeding ewes on account of failing mouths causes a loss to the whole sheep-farming industry. As Fraser (1949) says, "It would be of considerable advantage in sheep-farming if sheep could be relied on to keep perfect teeth to an older age . . . It is, however, simply not true to say, as is often said, that the best-fed sheep have the best teeth. The problem, and it remains an unsolved problem, is a much more complex one than that." The

* Hereinafter referred to as "5-year-old ewes"; similarly 4- and 6-year-old ewes are actually half a year older than described.

progressive deterioration in quality of sheep's mouths during the last 30 or 40 years proved on inquiry, however, to be a problem restricted to New Zealand.

It is commonly stated that unusually good mouths are retained by sheep on properties in the initial stages of grassing after the bush has been cleared by burning. The reason advanced for their subsequent deterioration is that necessary minerals (e.g. potassium and trace elements) have gradually disappeared or become unavailable. There were, however, a number of other important contemporary developments in sheepfarming practices, resulting in greatly increased carrying capacities, to which due consideration must be given:

1. Application of artificial manures, especially phosphates and lime (heavy liming might render unavailable from the soil trace elements required by the animal for its food).
2. Introduction of European grasses and clovers, replacing to various extents the low-yielding, fine, native grasses.
3. Closer fencing, leading to more intensive stocking.
4. Closer grazing.
5. Differences in chemical composition of the pastures, the shorter-grazed pastures being more succulent and richer in proteins and other constituents.
6. Easily available feed, resulting in heavier, less-active ewes.
7. Replacement of Merinos and other fine-woolled breeds by English breeds, almost exclusively Romneys in the North Island.
8. Heavier rates of stocking which might deplete the soil of necessary trace elements.
9. Since the introduction of age-marking, farmers have become aware of the variations and ranges in quality of sheep's mouths, even within their own flocks. Previously the ages of ewes were judged only by the teeth, and this is still the practice in some parts of New Zealand.

In general, the more improved the country the poorer the teeth, and, conversely, there have been reported improvements in mouths of sheep on country which, after being developed, has been allowed to deteriorate.

SCOPE OF THE INVESTIGATION

Because of the economic importance of the problem, and the lack of information concerning sheep's teeth, both from fundamental and farming aspects, an investigation of a fairly comprehensive nature was initiated some years ago at this College.

A preliminary survey showed that it was caused by attrition, not caries (decay)* and it was unlikely to be a simple problem of calcification since it was not associated with bone weakness, emaciation, depraved

* It is of interest to note that sheep chew vigorously "natural", fibrous foods, and their teeth are bathed in a copious flow of alkaline saliva, conditions regarded by the dental profession as conducive to sound, non-carious teeth in man.

appetite, or other symptoms of calcium or phosphorus deficiency. No reports had appeared in the dental research literature of pronounced attrition in teeth of farm animals, nor indeed, of any other species, except the preliminary reports on this problem by Barnicoat (1947, 1948).

Results discussed in the first 5 parts deal with the more applied aspects of the problem. The chemical and histological studies on fundamental aspects of the origin and nature of tooth wear, however, have demanded much more effort than these field and nutritional studies. They will be reported later.

As originally presented, the problem appeared to be nutritional, and initial stages of the investigation were chemical in nature. No evidence was found to justify extensive laboratory studies on the mineral (particularly the trace-element) or vitamin content of herbage, but the possibility that their level of intake or balance may be involved in this problem has never been overlooked.

Concurrently with the field surveys and nutritional studies described in these papers, related studies on certain fundamental aspects were undertaken in the laboratory, some of which are still proceeding. The principal laboratory work has been:

(a) Experiments on the solvent action of grass juice and rumen fluid on the inorganic matter of teeth.

(b) Separation of enamel and dentine for chemical analyses of constituents of importance to calcification, including the element fluorine.

(c) A comparison by means of examination under the microscope of teeth of different types, qualities, and ages, using thin sections of ground whole teeth, or of decalcified teeth.

(d) Tests on hardness of teeth.

(e) Preliminary observations on endocrine factors.

(f) Spectroscopic estimations of trace elements in enamels and dentines from six representative samples of teeth (by Soil Bureau, Department of Scientific and Industrial Research, Wellington).

(g) A comparative study by X-ray analysis of crystal size in enamels and dentines from six samples of teeth (Chemistry Department, Auckland University College).

(h) Electron microscope studies of the finer structure of teeth (Dominion Physical Laboratory, Lower Hutt).

Laboratory studies have not, however, established any differences in chemical, physical, or histological characteristics between teeth from various districts with different amounts of wear. The progresssive deterioration in the quality of mouths of sheep on country of increased carrying capacity is apparently due to their consumption of the actively metabolizing herbage of the improved species of pasture plants. The primary problem would therefore appear to be nutritional in nature.

As a result of the laboratory investigations, a number of fundamental problems relating to factors of practical importance, in particular the mode of eruption and development of incisors and the deposition of secondary dentine, have emerged, and will be studied.

Part 2. Effect of Condition of Teeth on Productivity of the Ewe

No information could be found on the relationship between the productivity of ewes and the states of their mouths. While there is no doubt that the practice of "mouthing" ewes is founded on experience, the traditional standards may require modification since the adoption almost exclusively of grassland farming, particularly in the North Island.

Experiments were therefore carried out to find to what extent the condition of the teeth affects the productivity of the ewe until 5 years of age. The mouths were judged at 5 years old, and since the ewes had been under similar conditions for 4 previous years, length of teeth, rather than the subjective grading system*, was used as the measure of quality whenever possible.

Results are shown in Table 1.

TABLE 1. CORRELATION BETWEEN AVERAGE PRODUCTIVITY OF EWES DURING 4 SEASONS (2-5 years of age) AND LENGTH OF CENTRAL INCISORS

Ewes	No. of Ewes	Correlation Coefficient (r)	Coefficient of Determination (%)
Farmed normally under "fat lamb" conditions			
Av. 0-6 weeks liveweight gain of lamb[1]	49	0.284*	8
Av. fleece weight	47	0.283*	8
Av. liveweight 6 weeks post-partum	47	0.050	—
Av. weight before mating (in March)	47	0.209	—
Similar animals used for milk secretion studies[2]			
Av. milk yield (3-9 weeks incl.)	32	0.140	—
Av. fleece weight	38	0.764**	58
Av. liveweight 6 weeks post-partum	37	0.224	—
Av. weight before mating (in March)	37	0.093	—

* significant at 5% level
** significant at 1% level

[1] An indirect measure of milk yield, as found from experiments by Barnicoat, Murray, Roberts, and Wilson (1956).

[2] Barnicoat *et al.* (1956).

Liveweights of ewes were not related to the extent of wear of the teeth, i.e. the heavier ewes had not worn out their teeth in their efforts to satisfy their physiological needs. On the other hand, correlations are consistent with the theory that ewes with better teeth were the higher wool yielders.

These indications are considered more critically in the next Tables (2 and 3) which show correlations between teeth and productivity of

* Grade scores were as follows: 9 excellent, 8-7 very good, 6-5 good, 4-3 fair, 2 poor, 1 bad, 0 "gummy". (10 classes average 4.5 points).

6-year-old ewes in their fifth lactation. They illustrate the influence of condition of the mouth of cast-for-age ewes on their subsequent performances under "fat lamb" conditions.

TABLE 2. CORRELATIONS BETWEEN LENGTH OF TEETH OF 6-YEAR-OLD EWES AND FLEECE WEIGHT

Description	No. of Ewes	Correlation Coefficient (r)	Coefficient of Determination (%)
(a) Under liberal "fat lamb" conditions	95	0.552**	30
(b) Ewes from milking experiment (similar conditions to (a))	14	0.594*	35
(c) Ewes from milking experiment (low plane of nutrition)	11	0.834**	70

(correlations (b) and (c) do not differ significantly, t (2,3 d.f.) = 1.24 (n.s.))

It is evident that the yield of wool of ewes at the "fat lamb" stage is closely associated with the state of the teeth, for coefficients of determination indicate that from 8 to 70 per cent of the differences in fleece weights were associated with variations in tooth quality. In Table 3 it appears that in the case of 6-year-old ewes maintained under liberal "fat lamb" grazing conditions, neither the lamb birthweight nor the ewes' milk yield (as judged by the lamb weight gain from 0–6 weeks of age) was affected. Ewes with poor teeth were distinctly lower in weight (i.e. in poorer condition) than others towards the end of lactation (October).

TABLE 3. EFFECT OF TOOTH QUALITY OF 5-YEAR-OLD EWES ON SUBSEQUENT PRODUCTIVITY UNDER "FAT LAMB" CONDITIONS

Experiment	Condition of Teeth at 5½ yrs. of age		Condition of Teeth after lambing 6½ yrs. age	Av. Ewe Live-weight (lb.)			Av. Lamb Weight (lb.)		Milk Yield (av. per day 3-9 wks. old) (oz.)
	Grade score	Length (1/10 in.)	Length (1/10 in.)	Mar.	Oct.	Diff.	Birth weight	0-6 weeks gain[1]	
(a)									
14 ewes	5 (good)	3.5	2.9	138	139	+ 1	10.7	27	—
15 „	0.8 (bad)	1.7	0.5	138	123	− 15	11.4	24	—
(b)									
12 ewes	3.4 (fair)	2.5	—	138	137	− 1	10.1	26	63[2]
10 „	1.4 (bad)	1.6	—	138	128	− 10	9.1	25	60

[1] An indirect measure of milk yield (Barnicoat *et al.*, 1956)

[2] Twin-bearing ewes.

Adverse effects of poor teeth on the productivity of the ewe under "fat lamb" conditions are greatest when the food supply is short, as a result of overstocking for example (Table 4 and Table 2). The "condition" of the ewe as measured by the average of liveweights before mating (early March) is also important.

The finding that under liberal conditions of grazing the state of the teeth of 5-year-old ewes had little influence on their subsequent productivity (fifth lactation) is supported by earlier results obtained in the course of studies on ewe milk yields (Logan, 1947). He found that milk yields (3-9 weeks inclusive) from 6 ewes with good, 14 with fair, and

TABLE 4. INFLUENCE OF QUALITY OF TEETH OF 5-YEAR-OLD EWES ON THEIR SUBSEQUENT PRODUCTIVITY UNDER NORMAL "FAT LAMB" CONDITIONS AND WHEN FOOD INTAKE IS RESTRICTED THROUGH OVERSTOCKING

Ewes[1]	Rate of Stocking per Acre	Teeth				Av. Milk Yield (3-9 wks. incl.) (oz./day)	Av. Wool Yield (lb.)	Av. Weight Loss (lb.) March (pre-mating) to October (lactating)
			Feb. 5½ yrs. old	Dec. 6½ yrs. old	Diff.			
		Grade	Length (1/10 in.)	Length (1/10 in.)	Length (1/10 in.)			
"High Plane" (17)	6/ac. (normal)	Fair	3.1	2.4	0.7	45	10.4	11
"Low Plane" (16)	9/ac. (50% overstocked)	Fair	3.0	0.8	2.2	29	7.5	41

	"High Plane" Ewes		"Low Plane" Ewes	
	Best 6 mouths	Poorest 6 mouths	Best 6 mouths	Poorest 6 mouths
Av. initial grade score	4.8	1.5	4.3	1.7
Av. milk yield (oz./day)	49	43	35	24
Av. wool yield (lb.)	11.3	8.2	8.2	7.2
Av. weight difference March to November (end of lactation)	2	−14	−27	−31

Correlation between initial grade-score of teeth and	High Plane	Low Plane[2]
weight loss of ewes (March-October)	−0.39	−0.504* (27)
milk yield (oz. per day)	0.30	0.540* (29)
Pre-mating ("saleyards") liveweight of ewe with milk yield	0.07	0.74** (55)

1. Four twin-bearing ewes in each group
2. Coefficients of determination shown in brackets.

11 with inferior mouths were similar, being on the average 45, 49, and 48 oz. respectively per day.

In another experiment, a group of seventeen 6½-year-old ewes with fair mouths (average central-incisor length 2-3 tenths of an inch) were retained under similar "fat lamb" conditions during their sixth lactation (i.e. until 7½ years old). All had lambs and were in good condition, and their teeth had worn, on the average, only 0.5 tenths of an inch.

On the whole it would appear that ewes with poor and even "gummy" mouths are at no disadvantage as producers of fat lambs, except when the food supply is short.

That the body and wool weights are adversely influenced by unsound mouths is not unexpected. It is, however, of considerable interest to find that the future of the lamb is safeguarded by its almost normal supply of tissues (birth weight) and food (ewe's milk) except when the food intake of the mother is drastically curtailed.

Part 3. Anatomical Factors and Dentition in relation to the Type of Sheep's Mouth

The desirable characteristics of sheep's mouths and their relative importance have not been adequately defined. Judgements of mouths made by individual farmers vary considerably, which is not surprising since they are to some extent based on the farmers' particular experiences, as well as on traditional standards.

An attempt was therefore made to evaluate the factors that determine quality in sheep's teeth by studying numerous jaws from a wide variety of farms. The opinions and average grade scores of several experienced farmers were initially taken as the standard.

Characteristics of the Individual Tooth

Of the 32 teeth in a sheep's mouth only the 8 incisors in the front lower jaw are concerned in this problem. (There are, strictly, only six incisors, the two outer teeth being canines.) Of these, the 2 central incisors, the first 2 permanent teeth to erupt, are the largest, and have a dominating influence on the condition and durability of the rest.

Sheep's teeth are hypsodont (Fig. 1), i.e. the long crown—the upper portion covered with enamel—does not appear in its entirety when the tooth is first cut, but erupts slowly as the sheep grows and matures, or at a more rapid rate in response to irritation of the pulp (Figs. 3, 4) through wear of the biting (incisal) edge.

It is contended that the length of time a tooth lasts under conditions causing wear is primarily dependent on the amount of tooth substance present, i.e. the size or weight of the crown, comprising both the visible and unerupted portions (Fig. 1). Results discussed in this paper are to a large extent based on this postulation.

Variations in Size of Teeth

Weight of Tooth as an Index of Tooth Substance. Newly erupted central incisors vary considerably in size (Table 5).

TABLE 5. VARIATIONS IN WEIGHT OF NEWLY ERUPTED CENTRAL INCISORS

	No. of Jaws	Average Weight (air-dry) per Tooth (g.)
Series (a)	55	0.74-1.28 (av. 1.02)
Series (b)	40	0.80-1.23 (av. 0.98)

Fig. 1.—Central incisors from 18-months-old (2-tooth) ewes. (x 2) illustrating

A. Hypsodont nature of sheep's teeth: (i) gum level indicated by grass stain; (ii) Junction of enamel-covered crown with root by pencil mark. The unerupted portion of the crown lies between (i) and (ii).

B. Variations in initial size: The crowns of a, b, and c weighed 0.9, 0.8, and 0.5 g. respectively, so the largest tooth (a) contained nearly twice the amount of "useful tooth substance" as (c); (b) a wide tooth, though rather less in weight than (a), is a better type of tooth.

Central incisors from slightly undershot jaws or from slightly over shot jaws,* which look (respectively) smaller and larger than average, did not differ notably in weight from those from normal mouths.

The largest tooth, from a very overshot jaw (not included in these averages) weighed 2.02 g.

The amounts of tooth substance remaining in the central incisors of 5-year-old ewes also varied greatly (Table 6).

TABLE 6. Average Weight of Central Incisor from 5-year-old Mouths

	Grade	No. of jaws	Av. weight of one air-dry central incisor (g.)	Classification according to row in Fig 2
Series (c) (51 jaws)	Good	10	0.79	2 (and 1)
	Fair	21	0.55	3 and 4
	Poor	17	0.55	
	Bad	3	0.33	5
	Origin			
Series (d) (48 jaws)	Farm (i)	12	0.83	2 (and 1)
	(ii)	6	0.55	3 and 4
	(iii)	18	0.41	
	(iv)	12	0.43	4 and 5

On the assumption that the weights of the central incisors of ewes at the 2-tooth stage (about 15 months old) were representative of the original weights of teeth of similar ewes kept until $5\frac{1}{2}$ years of age (Table 6), it follows that:

(a) During 4 years of use, central incisors of the better, unworn mouths lost, on the average, 0.2 g. of tooth substance, and those of the poorest mouths 0.7 g., equivalent to average yearly losses of about 0.05 g. and 0.17 g. respectively per tooth.

(b) Since the roots of incisors from "gummy" teeth weighed about 0.3 g. on the average, the weight of useful crown remaining at 5 years varied from about 0 to 0.5 g.

(c) The weight of an incisor at the initial 2-tooth stage varied from about 0.8 to 1.3 g., a range of 0.5 g., which is of the same order of weight difference between the best and poorest teeth from 5-year-old ewes.

It would seem that variations in duration of teeth in a flock might be accounted for by their initial differences. In practice the problem is not as simple as this, and variations between mouths of sheep maintained under similar conditions cannot be ascribed solely to initial

* Incisor teeth projecting forward of their normal position are described as *overshot*, those meeting the top pad behind this position as *undershot;* these terms are used in exactly the opposite sense in America, Australia, and Britain.

differences in the size of the teeth. In addition to anatomical factors, the rate of wear is modified by the hard plug of secondary dentine deposited in the pulp canal as the tooth wears. There is no doubt, however, that original size of tooth is an important factor determining its duration. This matter is also discussed further in Part 5.

Length of Enamel Crown. Central incisors, in their original, unworn condition, vary considerably in length, especially the enamel crown, much of which is below gum level at this stage. From measurements of 120 representative jaws, the results in Table 7 were obtained:

TABLE 7. LENGTH OF NEWLY ERUPTED CENTRAL INCISORS (at 15-18 months)

	Length (1/10 in.)
Enamel crown, total (erupted plus unerupted)	6 to 12 (av. 9)
Root	3.5 to 5 (av. 4)
Total	11 to 15 (av. 13)

The enamel crown had practically all disappeared from teeth of "gummy" ewes, the rate of wear being in extreme cases 2 to 3 tenths of an inch per year. Since roots of central incisors of 5-year-old ewes varied in length from 4 to 6 tenths of an inch, they were larger than roots of newly erupted teeth, and appeared to have grown.

Width of Tooth. Because of the tapering of incisor teeth, their width at gum level decreases as they erupt (Table 8).

TABLE 8. WIDTH OF CENTRAL INCISORS AT GUM LEVEL

	Age of Ewe	Number of Jaws	Width at Gum Level (1/10 in.)
Series a	2 years	20	2.4
	3 years	20	2.1
	4 years	20	2.0
	5 years	20	1.8
Series b	5½ years	10 Good	1.8
		21 Fair	1.7
		17 Poor	1.6
		3 Bad	1.4

VARIATIONS BETWEEN EWES' MOUTHS

In addition to differences in quality between teeth of sheep in various districts, wide variations occur between those of animals bred and maintained on the same property.

In Fig. 2 are shown life-sized photographs illustrating the range of mouths encountered among 5-year-old Romney ewes in New Zealand.

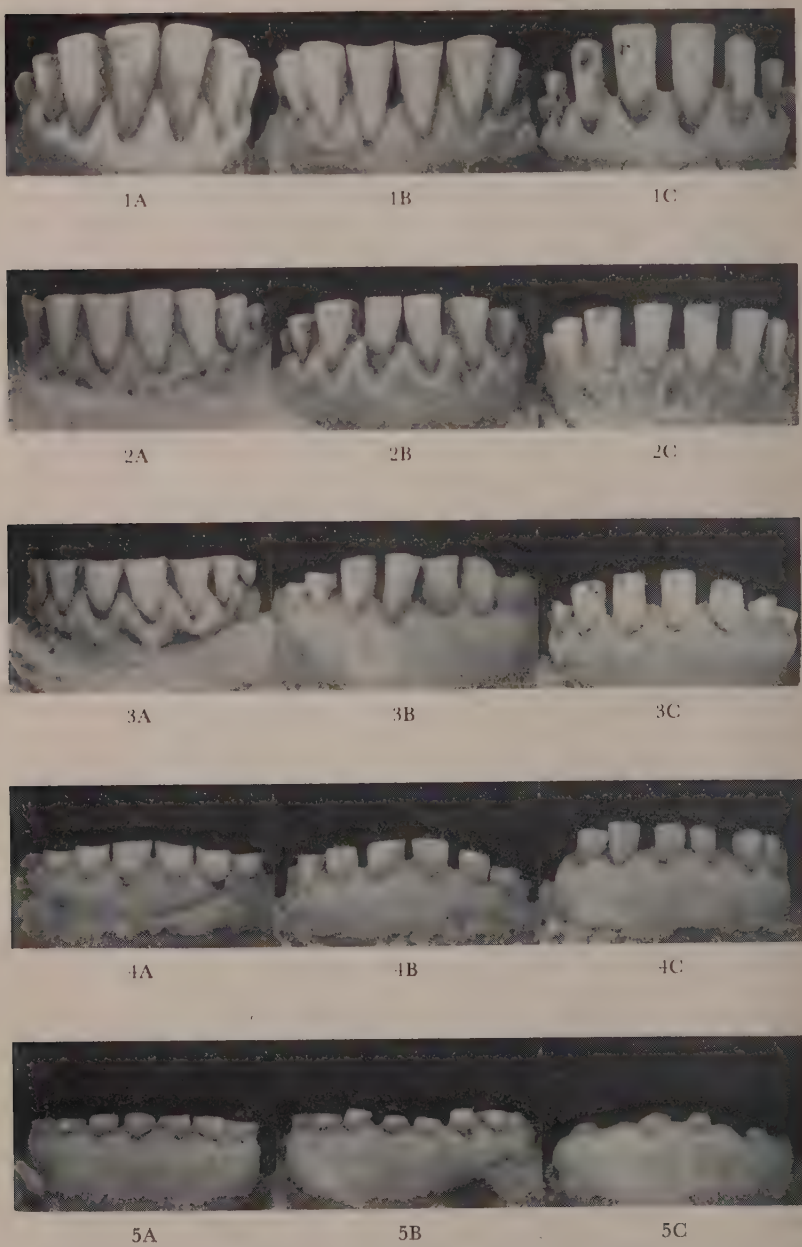

Fig. 2.—Variations in mouths of 5-year-old Romney ewes. (x 1·
Average lengths ($\frac{1}{10}$ in.) and grade scores of the 5 rows are: *1.* 6.5, 6–7; *2.* 4.5; 5-5; *3.* 3.5, 3.5; *4.* 2.5, 2-2.5; *5.* 0.5, 0-1.

In an average flock, the majority of the 5-year mouths vary between, or span, 2 rows of the chart, but an even greater range is found in the largest flocks.

As emphasized recently by McIntosh (1953), it is not possible under New Zealand conditions without considerable local knowledge on the part of the judge to give more than a rough estimate of the age of full-mouthed ewes from the condition of their teeth. Throughout this investigation it has been necessary to employ statistical methods for differentiating the results of such diverse experimental material.

Variations in quality of teeth of cast-for-age ewes from one flock can often be traced from records to differences in teeth and jaw conformation that have persisted since the earliest stages, and appear to be inherited. Because a small proportion of aged ewes, from a property notable for poor teeth, retained good mouths, a systematic study was made of more than 100 ear-tagged ewes from the 2-tooth stage (15 months) until 5 or 6 years old. From these results have been prepared the standards recommended for differentiating mouths of 2-tooth ewes for purposes of culling or retention in the flock (Part 5).

Effect of Wear on the Appearance and Size of Sheep's Teeth

Sheep's teeth normally wear to some extent with use, the bevelled tip ("chisel" mouth) being abraded to a flat surface biting against the hard pad of the top jaw, which develops corresponding shallow depressions.

Long, unworn teeth (1A, Fig. 2) are found nowadays in 5-year-old ewes in only a few districts. Such teeth are, in fact, not favoured by most farmers, being regarded as easily loosened and levered out through biting hard substances, such as roots. This consideration does not seem of importance under conditions of grassland farming, however.

As the tooth wears, the pulp canal becomes closed with a hard plug of secondary dentine deposited by certain special cells of the pulp (Fig. 3b). Since this plug is usually stained darker than the surrounding true dentine (Fig. 4A), it has the appearance of decay, but caries has not been detected in any of the teeth examined in the course of this investigation.

At 5 years of age, sheep's incisors have usually worn to level, biting surfaces (Rows 2-4 Fig. 2), chiefly dentine with a surrounding layer of the harder enamel and a plug of secondary dentine. Most of the crown has erupted, as a rule, at this stage and badly worn teeth (Row 5, Fig. 2) have erupted completely in response to excessive wear. Most of the biting surface of badly worn, short teeth, therefore, consists of secondary dentine, which is a very hard substance. Ewes with teeth like 5 B and C (Fig. 2) are described as "gummies" and are frequently regarded as worthless for breeding purposes and are sold to the freezing works.

It is unusual nowadays to find sheep with "chisel mouths" (1A, Fig. 2). Whether the attrition responsible for wear is solely the result of mechanical wear (abrasion) or whether it is initiated by erosion caused by chemical action of the grass or clover juice is still under investigation in this laboratory. There are good theoretical grounds for assuming that certain substances in actively growing herbage would have a dissolving

3A 3B

Fig. 3.—Longitudinal sections of sheep's teeth. (x 2)

A. Transparent section of finely ground 5-year-old worn tooth, stained to bring out details: the crown (upper half) is composed of (i) outer layers of enamel, thicker on the front side, surrounding (ii) dentine, the major constituent, and (iii) the central pulp chamber with a plug of secondary dentine. The root, covered with cementum, forms the lower half of the tooth.

B. Sections of teeth illustrating changes due to wear and age: (a) newly erupted central incisors and (b) worn central incisors from a 5-year-old ewe. Note (i) shortening due to wear, (ii) narrowing of the pulp canal, (iii) closing of worn end of pulp canal with a plug of secondary dentine (outlined by a crack along the left side), and (iv) apparent thickening of the root.

4A 4B

Fig. 4.—Excessively worn mouth of 4-year-old ewe. (x 1)

A. Showing caries-like appearance due to staining of plugs of secondary dentine.

B. X-ray photograph indicating absence of caries. There are marks showing gum level. The manner in which the unerupted portions of the teeth fit in their sockets is also evident.

action on the calcium salts of the teeth and that the effect of this solvent action would be increased by the abrasiveness of the fibre in the grasses.

RATES OF ERUPTION OF TEETH

Seasonal Influence

Eruption rates of central incisors of 34 ewes on improved pasture were followed at 3-monthly intervals by means of measurements of wax impressions of file nicks during three years (2-5 years of age). The results are summarized in Table 9.

TABLE 9. RATES OF ERUPTION OF CENTRAL INCISORS (average for 34 ewes)

	Aug.-Oct. Spring	Nov.-Jan. Summer	Feb.-Apr. Autumn	May-July Winter	Total for 3 years
Total length erupted—tenths of an inch	0.69	1.13	1.08	(−0.06)	2.90
% of total	24	39	37	Nil	100

There was a marked seasonal effect, with consistently no movement during the three winter periods, but considerable movement in summer and autumn, presumably in response to the greater wear in the preceding spring and summer periods (Table 26).

Apparent Regrowth of Teeth of Aged Ewes

Growth of teeth has been reported in the case of ewes transferred from sparse and usually somewhat overgrazed pastures on hill country to certain fat-lamb areas in the Waikato and Manawatu on wet or swampy land notable for soft grasses. The explanation is that in certain cases, particularly with close, wide teeth (2A and 3A, Fig. 2) a considerable portion of the crown may be unerupted. This will continue to erupt and, if the ewes are given ample feed and the pasture is soft, the rate of eruption may exceed the rate of wear. The result is that, rather surprisingly, the partly worn teeth grow longer. Results in Table 10 illustrate this phenomenon.

TABLE 10. INCREASE IN LENGTH OF PARTLY WORN TEETH OF 5-YEAR-OLD EWES TRANSFERRED TO SOFT PASTURE

	Observed Change in Length after 1 Year (1/10 in.)	
(a) *Controls* (39 ewes on perennial ryegrass-white clover (fat-lamb) pasture)	Decrease 0 – 1.5	Average 0.07
(b) *Experimental* (9 ewes on mixed pasture on damp country)	Increase 0 – 1.7	0.08
Average difference in favour of (b)		1.5 increase

Age of Ewe in Relation to Number of Teeth Cut

It is a traditional practice to estimate the age of sheep by the state of their teeth. During their first 3–3½ years of life, the estimate depends on the number of permanent teeth cut.

Typical results from records of 200 ewes on 4 farms on easy hill country are shown in Table 11. It is apparent that because of the uneven rates of eruption of sheep's incisors, it is difficult to determine the age of the animals accurately. It was even difficult to decide in several mouths after reference to the previous (42 months) records, whether the lack of corner teeth was due to their rapid wear, or to their non-appearance.

TABLE 11. VARIATIONS IN NUMBER OF TEETH CUT AT DIFFERENT AGES (expressed as percentages)

No. of Teeth Cut	Age of Ewe (months ± 1)					
	18	21	30	33	42	54
0	3	—				
1	—	1				
2	94	69	1			
3	3	6	3			
4		23	33	1		
5		1	8	1		
6			53	96	32	
7			1	1	7	
8			1	1	61	all?

Plane of Nutrition in Relation to Eruption Rate

It is widely held that "forced feeding", particularly with dry feeds and concentrates as supplied to some stud sheep, causes teeth to erupt early and from this farmers conclude that teeth of sheep on lush European grasses will be similarly affected. It is further contended that early erupting teeth will not be properly mature and will therefore be softer and less resistent to wear by attrition.

In Table 12 the average number of teeth erupted at various ages in mouths of sheep on different types of country is shown. While there was a tendency for the mouths of ewes on the easier higher-carrying-

TABLE 12. RELATION BETWEEN TYPE OF COUNTRY AND NUMBER OF TEETH CUT

Type of Country	Ewes per Acre	No. of Teeth Cut at		
		18	30	42 months
(a) Steeper, higher hill country (3 farms, 140 ewes)	1–1½	2.00	4.5	7.1
(b) Easier hill country (3 farms, 120 ewes)	2½–3	1.97	5.3	7.6
(c) Fat-lamb conditions	6–7	2.20	5.3	8.0

capacity land (b) to erupt early, these mouths lasted, on the average, just as well as others (a).

COMMON FAULTS IN SHEEP'S MOUTHS AND THE EXTENT OF THEIR OCCURRENCE

"Spreading" of Teeth due to Age and Wear

Sheep's mouths appear to "open up" as they wear (compare column C with A, Fig. 2). It is generally believed that this is due to spreading of the teeth, but this is not so, since measurements of casts of mouths of individual ewes made annually* (Fig. 5) show that there is no increase in distance between the inner extreme boundaries of teeth of the same ewes when "full-mouthed" (about 4 years old) and 3 years later when they had assumed an "open" appearance.

5A 5B

Fig. 5.—Casts of sheep's mouths. (x 1)

A. 4-year-old ("fresh full mouth")—close slightly worn teeth, and

B. the same mouth at 7 years, when well worn and "open", giving an appearance of spreading.

Distances between teeth along the lines indicate a tendency to shrink rather than spread.

Unworn, or slightly worn, teeth tend to remain close (1A and 2A, 1B and 2B Fig. 2). If, however, they wear down rapidly, they erupt more rapidly in consequence. Since the unerupted portion of the crown and root of each incisor is held in the socket in the gum (Fig. 4b), these teeth are guided up in fixed relationship to one another and remain at the same distance apart, at least until the ewes are 5 or 6 years of age. Because of their tapered shape, lower portions of the teeth, originally below gum level, erupt in response to wear and become themselves the visible crowns. The successive portions forming the visible crown become narrower, and spaces between them increase.

"Shrinking" of the Gums

Levels of lines of stain or tartar at the base of the crown appear to result from shrinkage of the gum. Measurements of casts of mouths of individual ewes at yearly intervals gave no evidence of change in gum level, however. The lines would appear rather to be the effect of stains from the lush herbage on the newly erupted (and possibly not fully matured) enamel crown.

* By Messrs. A. C. Morton, W. M. Webster and G. S. Wilson for earlier studies on sheep's mouths at this College.

Defects in Conformation of the Jaw

The incisors in a normal sheep's jaw should align themselves with the upper pad, and there should be no perceptible ridge between it and the front edges of the teeth. Many ewes' mouths do not attain this standard, and there are great differences in this respect even between averages for flocks. Incisor teeth projecting forward of their normal position are described as *overshot*, those meeting the top pad behind this position as *undershot**. The undershot jaw is one of the commonest mouth defects in New Zealand Romney ewes. Hitchin (1948) found both defects common in certain breeds of sheep in Great Britain.

Undershot Jaws. It is believed by most farmers that sheep with very undershot mouths are at a disadvantage because they cannot graze as closely to the ground as can animals with normal mouths. It is known, too, that undershot jaws are strongly inherited (Part 5), consequently ewes with noticeably short jaws are customarily culled at as early a stage as possible. From results presented in Table 13 based on observations made on 463 ear-tagged sheep (on 12 different farms

TABLE 13. THE EFFECT OF UNDERSHOT CONFORMATION ON THE QUALITY OF SHEEP'S TEETH

Farm Number in Order of tooth Quality	As observed		Mouths Not Showing Undershot Tendencies	Mouths with undershot tendencies		Differences in Final Grade Score in Favour of Mouths Free of Undershot Appearance
	Average Final Grade Score	Central Incisors Length (1/10 in.)	Average Final Grade Score	Average Final Grade Score	% in Flock	
1	6.6	4.4	6.6	6.6	15	0.0
2	6.2	4.1	6.8	5.3	40	1.5
3	5.1	3.4	6.3	3.0	36	3.3
4	3.7	2.7	4.1	2.9	33	1.2
5	3.6	2.5	6.0	2.9	77	3.1
6	3.1	2.3	4.0	2.4	58	1.6
7	2.7	2.7	3.0	2.0	28	1.0
8	2.6	1.6	3.6	2.1	67	1.5
9	2.5	1.8	4.7	1.4	66	3.3
10	2.2	1.7	3.2	1.8	72	1.4
11	2.0	1.7	3.0	1.3	60	1.7
12	1.3	1.1	2.2	1.0	75	1.2
Av.	3.5	2.5	4.5	2.7	52	1.8

* These terms are used in exactly the opposite sense in the United States of America, Australia, and Britain.

in the North Island), followed individually from the 2-tooth stage until $5\frac{1}{2}$ years of age, it is concluded that much less-pronounced degrees of undershot conformation (Figs. 6, 11, 15) are in fact inimical to tooth quality, because:

(1) There were considerable differences between average grade scores for normal mouths and for those with even a slight tendency to undershot conformation.

(2) Many of the slightly undershot mouths of sheep from properties on the lower part of the list in Table 13 were in a "gummy" condition when 4 or 5 years old.

(3) Grade scores for "not undershot" (but not otherwise faultless) jaws indicated the type of mouth to be expected on the farms if undershot defects were entirely eliminated. The average difference is nearly 3 points in a 10-point grading system, corresponding to at least one extra year's production from the ewe under "fat lamb" conditions.

(4) On unimproved hill-country farms which carry the best mouths (Nos. 1 and 2, Table 13) undershot jaws did not prove to be nearly so disadvantageous as on the more heavily stocked improved pastures. On the other hand, there were properties (Nos. 5 and 9) where the high proportion of undershot mouths contributed markedly to the lowering in average quality of mouths in the flocks.

In Table 14, data from 362 sheep on 11 of the farms (i.e. excluding No. 7) considered in Table 13 are re-arranged to show the influence of different degrees of undershot conformation on the quality of mouths of 5-year-old ewes.

TABLE 14. GRADE SCORES OF 5-YEAR-OLD MOUTHS WITH UNDERSHOT TENDENCIES (362 ewes)

Description of Alignment of Teeth and Pad	Average Grade Score	% of Total Mouths
All mouths	3.5	100
Normal mouths (i.e. no adverse comments recorded)	5.1	41
Slightly undershot—about $\frac{1}{16}$ in.—just perceptible by feeling	3.1	17
Undershot about $\frac{1}{8}$ in.	2.6	20
$\frac{1}{4}$ in. or more undershot—usually rejected at an early stage	1.4	12
Mouths with other faults	2.0	10

Overshot Jaws (*Fig 7. and 7 A and B*). This fault was not found to be as common as the undershot jaw. In one group of 101 5-year-old ewes, 7 cases were detected, of which only one was really pronounced. In another group, 8 ewes out of 97 had slightly overshot mouths. These findings appear to be typical of other flocks.

Length and Size of the Lower Jaw. It is generally considered (Part 5) that the fit of the incisors with the upper pad is determined by the length of the lower jaw, and that undershot and overshot defects result from a deficient or excessive growth of the mandibular bone.

In practice, farmers pay considerable attention to the size and appearance of the lower jaw, since it is believed that a massive lower jaw indicates strength and ability to graze, while breadth of muzzle implies the presence of a wide expanse of teeth for biting and chewing. In a general way these assumptions are correct, but there are certain qualifications:

(i) Since no correlation between the weights of 24 air-dry jaws (121 g. to 220 g., av. 177 g.) and total length of enamel crown present in the "nicked teeth" experiment (Tables 9 and 26) was found ($r = 0.297$ N.S.), it follows that good teeth are not restricted to massive jaws.

(ii) A wide lower jaw with wide evenly placed teeth (as in Figs. 8 and 9) represents an ideal mouth.

(iii) On the other hand, a wide lower jaw with narrow teeth wears rather rapidly, giving an appearance of spreading. This openness is undesirable.

(iv) A narrow jaw with narrow teeth wears quickly, and though the teeth remain close, the final mouth will be rather a poor one (Figs. 10, 11, 12).

(v) In a narrow jaw with wide teeth, the teeth are overcrowded, which will often cause overlapping of the central incisors, giving rise to:

Deep "V" in Central Incisors (Fig. 13)

This defect occurred in about 10% of the mouths in many flocks, and in over 50% on one farm where it was a serious defect. It is not a common fault on unimproved pastures.

Fig. 6.—Slightly undershot jaw (about $\frac{1}{8}$ in. undershot).

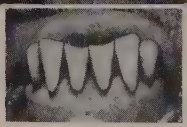

Fig. 7. Very slightly overshot jaw.

7A 7B

7A and 7B "Five-year-old" mouths from ewes with slightly overshot jaws showing "eaten down in front" appearance
A. relatively unworn mouth. B. badly worn mouth.

NOTE. Figs. 6 to 15, left to right, 2-tooth to full mouth, all × $\frac{2}{3}$

Fig. 8.—Wide teeth.

Fig. 9.—Wide teeth.

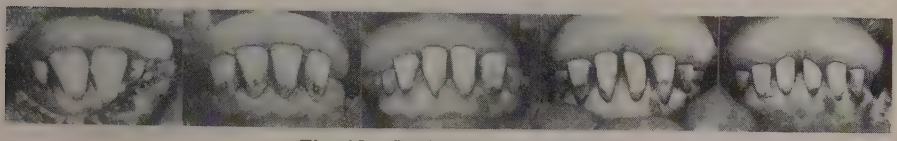

Fig. 10.—Rather narrow teeth.

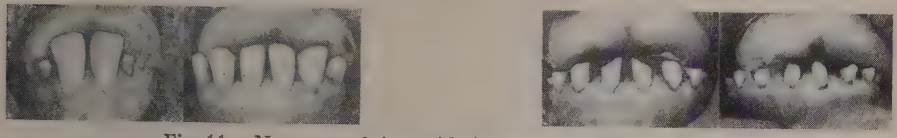

Fig. 11.—Narrow teeth in a wide jaw; very slightly undershot.

Fig. 12.—Narrow teeth in a wide jaw.

Fig. 13.—Overlapped central incisors changing to deep "V".

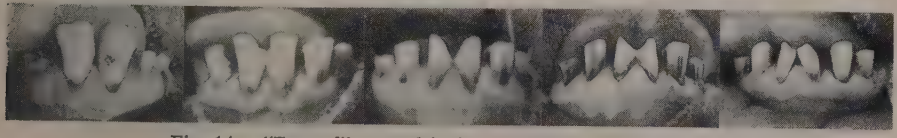

Fig. 14.—"Fanned" central incisors changing to "pointing".

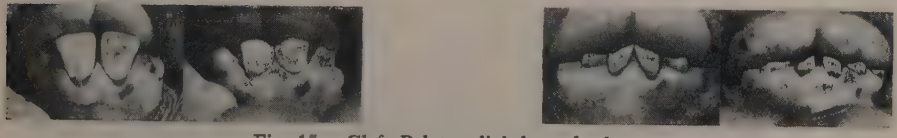

Fig. 15.—Cleft Palate; slightly undershot.

"Pointing" (inwards) of Central Incisors (Fig. 14)

This is rather a common fault in the worn, open mouths of some flocks.

Cleft Palate

Teeth in mouths with cleft palates follow the shape of the cleft in the pad, and are of characteristic appearance, being slightly longer towards the middle (Fig. 15).

Discoloration

The colour of sheep's teeth depends chiefly on the type of pasture they have recently grazed, lush green pastures causing considerable staining. Nevertheless, some of the best teeth had a smooth surface that did not discolour readily (Fig. 8). "Mottled" teeth, resembling fluorosis were found occasionally in individual ewes in flocks on areas not affected by an excess of fluorine

Fluted Teeth

There does not appear to be any association between fluting and lack of resistance to wear. Nevertheless the best teeth were usually full and rounded and consequently fluting is not prominent on this type of incisor.

RELATIVE IMPORTANCE OF VARIOUS ANATOMICAL FACTORS ON QUALITY OF SHEEP'S MOUTHS

From the foregoing sections it is apparent that a number of factors contribute to quality in sheep's mouths, and these factors are to a considerable extent interrelated (e.g. width with closeness; narrowness with openness). As shown in Tables 15 and 16, the bigger teeth are rated highest, and this criterion also holds in practice, as shown by the results recorded in the following table.

These results clearly indicate that (a) the most desirable mouths for 5-year-old ewes are those with close wide teeth, and (b) mouths

TABLE 15. AVERAGE GRADE SCORE FOR MOUTHS OF 5-YEAR-OLD EWES CLASSIFIED ACCORDING TO TYPE (% of ewes of each type shown in brackets)

	Type of Mouth					
	Under-shot	Open	Close	Narrow teeth	Wide teeth	All Mouths
Series (a)						
370 ewes from 10 farms on improved pastures	2.6 (47)	1.8 (11)	3.2 (30)	1.7 (25)	4.6 (28)	3.3 (100)
Av. length (1/10 in.)	2.4	1.8	2.2	1.8	2.9	2.6
Series (b)						
90 ewes from 2 unimproved pastures	6.0 (28)	5.5 (7)	6.5 (31)	5.8 (18)	7.0 (30)	6.3 (100)
Av. length (1/10 in.)	3.6	4.3	4.1	4.0	4.5	4.2

of the best type, from unimproved pastures, while exhibiting about the same proportions of faults, were relatively less affected by these faults than mouths of lower average grade from improved properties.

The following results from mouths of 100 5-year-old ewes maintained on improved country support this observation.

TABLE 16. ASSOCIATION BETWEEN FACTORS DETERMINING QUALITY OF SHEEP'S MOUTHS

Type of Mouth	Average Grade Score	Average Length (1/10 in.)
Narrow and undershot	1.7	2.1
Narrow and open	1.7	2.4
Narrow and close	4.0	3.8
Wide, close, and undershot	3.5	3.0
Wide and close	5.5	3.6
All mouths	2.7	2.7

In the following table, correlations between measurements of the central incisors and grade scores of the mouths are shown.

TABLE 17. CORRELATION BETWEEN GRADE SCORE OF TEETH AND MEASUREMENTS OF THE CENTRAL INCISORS

Correlation	Age of Sheep	Correlation Coefficient (r)	No. of Observations	Coefficient of Determination (%)
Grade score with:				
weight (air-dry)	5 years	0.71**	23	50
length above gum	„	0.59**	23	39
area ("size")	„	0.49*	19	25
width at gum level	„	0.65**	19	42
Width with length	5 years	0.51*	19	26
Width at gum level with air-dry weight	2 years	0.68**	40	46

Grade scores used for this table were the average of those allotted by several experienced farmers.

It is evident from the foregoing tables that wide, long teeth with no appearance of undershot conformation are most highly prized in practice.

Part 4. External Influences on the Quality of Sheep's Teeth

In the preceding sections factors responsible for differences in rates of wear of teeth of sheep maintained under similar conditions have been discussed.

Since the problem originally appeared to be nutritional, the initial plans for this investigation envisaged an extensive series of laboratory studies involving chemical analyses of teeth and pastures from selected areas and properties carrying sheep with notably different types of mouths. It was evident at an early stage, however, that the surprising variations between teeth of sheep maintained under similar, and even identical, conditions had first to be explained.

Results recorded in the previous sections were, in fact, obtained at later stages of this investigation but they have been combined and presented at this early stage, as they logically follow the introductory section dealing with the effect of tooth quality on the productivity of ewes.

This section deals with factors responsible for variations in tooth quality between sheep bred in different regions of the country—the problem of wear in sheep's teeth as originally presented for investigation.

The results are discussed under three major headings: Environmental factors, managemental factors, and nutritional factors.

Environmental Factors

Regional Effects

The map of New Zealand showing variations in average length of teeth in mouths of 5-year-old ewes (Fig. 16) was prepared from information supplied by Stock and Station Agents' Associations throughout the country. In order to obtain objective measures of tooth quality for purposes of comparison the photographic chart (Fig. 2) was distributed and used as a reference standard. Data were classified in 5 classes on the basis of average length of central incisors of the majority (about two-thirds) of the mouths of 5-year-old Romney* ewes bred on farms typical of the district. It has been shown (Part 2) that average length of central incisors is a reasonable and objective measure of tooth quality, especially when large numbers of ewes are being considered, and this characteristic was therefore used to differentiate geographical regions in terms of their effects on the teeth of grazing sheep. No attempt was made to grade the mouths—the lower the classification number the longer, and therefore the less worn, the teeth. (In practice farmers would usually prefer Class 2 to Class 1 mouths.)

By comparing this map with others relating to physical and botanical environments† certain generalizations can be made.

* In parts of the South Island measurements from other breeds, particularly Corriedales, were included, but this would not affect the results.

† (ia) Geological map of New Zealand (1947) N.Z. Geological Survey, Department of Scientific and Industrial Research.
(ib) Maps of the New Zealand Soil Survey (1948 and later) Department of Scientific and Industrial Research.
(ii) "New Zealand Landforms" W. H. Wallace, *N.Z. Geographer 11:* 17. (1955)
(iii) "Average Annual Rainfall in New Zealand". New Zealand Meteorological Office 1930.
(iv) Pasture Survey Map North Island E. A. Madden 1939.
South Island S. I. Hilgendorf 1935.

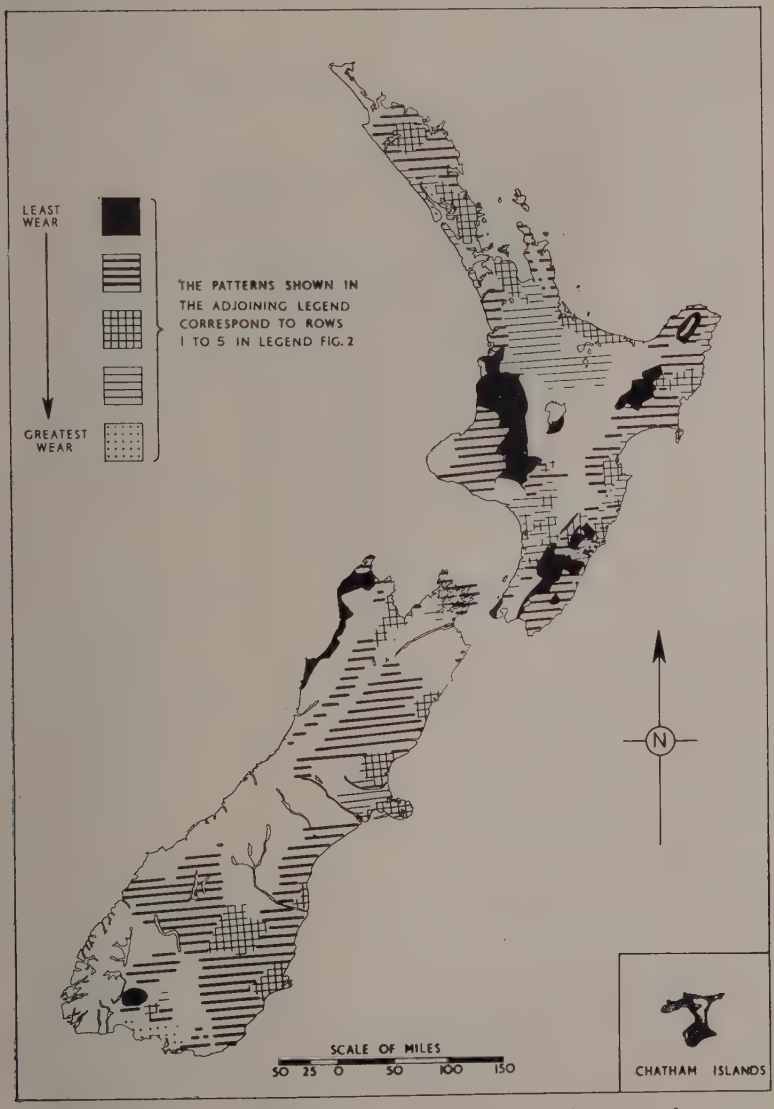
LEAST WEAR
GREATEST WEAR
THE PATTERNS SHOWN IN THE ADJOINING LEGEND CORRESPOND TO ROWS 1 TO 5 IN LEGEND FIG. 2
N
SCALE OF MILES
50 25 0 50 100 150
CHATHAM ISLANDS

Fig. 16.—Map of New Zealand illustrating differences in extent of wear in sheep's teeth (of 5-year-old Romney ewes bred on the properties). Prepared from information supplied by district branches of the New Zealand Stock and Station Agents' Association.

Geological Formation. There is no similarity between the map of variations in tooth length and the geological map of New Zealand.

Soil Types. Teeth showing least wear tend to occur on the zonal, steeper hills, apparently because of the climatic conditions and vegetation asssociated with them, rather than the nature of the soil.

On sandy soils (e.g. Bulls, Fordell, Te Awa Research Station) sheep's mouths are such as would be expected from the nature of the pastures. Sheep on sandy coastal areas (Kaipara, Foxton—Rangitikei) are stated to have badly worn mouths, possibly because of the sparse and dried up pasture.

Teeth do not wear down excessively on pumice land (Lake Taupo, Waikato), contrary to what might be expected from the effect of pumice on farm implements.

Mouths of sheep in Canterbury, particularly in the higher country, are worn more than those on similar North Island country, because of the abrasive action of fine river silt and loess distributed by wind. (Small local areas throughout both islands are adversely affected by wind- or water-deposited river silt). Abrasion due to mechanical causes is well known both here and abroad. This problem is quite distinct from that of progressive deterioration of mouths on improved country, which is the central problem of this investigation.

On swampy areas (e.g. parts of the Waikato and Manawatu) sheep's teeth remain long, apparently because of the soft herbage resulting from high moisture content of the soil.

Hills with limestone caps and outcrops do not necessarily (as is so often categorically stated) carry sheep with "magnificent mouths". Sometimes the mouths are rather poor (e.g. Dannevirke area).

While the evidence from the map suggests broad correlations with different kinds of country, it does not indicate any clear connection with known "trace element" deficiencies or imbalance. The present state of knowledge, however, is insufficient to discount the possibility of this completely.

Topography

The best mouths occur, as a rule, on the higher country, probably as a result of:

Climate and Rainfall

The least-worn teeth are found in mouths of sheep from the high-rainfall areas (45–50 in. per annum or more). Distribution of precipitation, especially in summer, rather than actual rainfall, is the crucial factor, and dews and mists undoubtedly contribute to maintaining succulence and softness of the grasses, which appears to be a major factor in preventing wear in sheep's teeth. (Teeth of aged ewes are better than usual after a series of wet summers). Wind militates against this as it dries up and toughens the pasture and in some areas distributes abrasive matter as well.

Under liberal grazing conditions on improved pastures there was no evidence (Table 26) that teeth wore down rapidly in winter through abrasion resulting from contamination of herbage with mud and worm casts.

Herbage

The nature of the herbage consumed appears to have a dominating influence on the quality of sheep's teeth.

TABLE 18. VARIATIONS IN TEETH OF 5-YEAR-OLD EWES FROM ONE DISTRICT

Farm No.	Grade Score†	Av. Length Central Incisors (1/10 in.)	Rate of Stocking (ewes/acre)	Pasture Species Grazed	Class and Description (N.Z. Soil Survey data)	Remarks
1	1.3	1.1	3	Dogstail, ryegrass, Yorkshire fog, white clover	114a Taihape silt loam	Overstocking
2	2.0	1.6	3	do	(a) *Parent material* mudstone (b) *Original vegetation* forest	do
3	2.2	1.7		do	(c) *Rainfall* 35–50 in.	do
4	2.6	1.7	2—	Danthonia dominant, ryegrass, clover, dogstail	(d) Steep to very steep (e) 1,000–1,500 ft. above sea level	do Country dries out easily
5	3.1	2.3		do		
6	3.7	2.7		do		Heavy cattling
7	2.5	1.5	2+	do	29H Omakere silt loam	
8*	3.6	2.5		Dogstail, ryegrass, Yorkshire fog, clover	(a) mudstone (b) forest (c) 45–70 in. (d) moderately steep	Heavy cattling
9	5.1	3.4	1½	Danthonia dominant	116b Whangamomona silt loam	
10	6.2	4.1		Danthonia and browntop	(a) mudstone and sandstone (b) beech forest (c) 50–80 in. (d) steep and very steep (e) 2,000–2,500 ft.	
11	6.6	4.4	1–1½	Danthonia and mixed grasses	113b Pukeokahu silt loam (a) limestone, sandstone, mudstone (b) Forest (c) 40–50 in. (d) steep (e) 2,000–3,000 ft.	

* + 29cH—mudstone and greywacke

†Grade score	Classification of 5-year-old-ewes (as fat-lamb producers)
> 5	2-year mouths
about 3.5	1 & 2-year mouths
,, 2.5	Chiefly 1-year mouths
< 2.5	1-year mouths and "gummies"

In general the longest, practically unworn Row 1 mouths (Fig. 2) including "chisel" mouths, are found in two different regions of New Zealand (a) scrub or tussock country, with rainfall of 60 in. or more, where sheep are very thinly spread, their feed consisting of native grasses, weeds, and softer portions of scrub (e.g. parts of the King Country and contiguous areas on the west coast; part of the South Island remote from the Southern Alps; and (b) unimproved country, 50 in. or more rainfall, with browntop-dominant pastures (e.g. Terawhiti and parts of Wairarapa and Manawatu) although such land is now merely a remnant among highly improved dairying and fat-lamb country.

Row 2 mouths (Fig. 2) are found in sheep bred on (a) "paspalum country" with high rainfall (50 in. or more) principally North Auckland; (b) country with a 50 in. or higher rainfall on which danthonia or browntop predominates (Coromandel Peninsula; east coast of North Island; Cape Terawhiti); (c) high country carrying tussock and native grasses (30–60 in. rainfall) such as the foothills of the Southern Alps, and (d) areas sown with short-rotation ryegrass and cocksfoot, restricted to parts of Canterbury.

TABLE 19. Variations in Mouths of 5-year-old Ewes from One Flock after Distribution to 4 Different Farms for 4 Lactations

Farm No.	Soil Type	Pasture Species	Altitude (ft.)	Rainfall (in.)	Av. Type of Mouth (Row No. in Fig. 2)	Approx. Rate of Stocking (per acre)	Remarks
1	13 Tokomaru silt loam	Perennial ryegrass, white clover	below 200	40	4	6	Heavily top dressed—liberally grazed
2	do	Browntop, sweet vernal, Yorkshire fog, ryegrass, clovers	below 200	40	4–5	3½	Little top-dressing—overstocked
3	118a Pohangina silt loam	(a) hills as for 4 (b) river flats as for 1	900–1,200	45–70	3–4	(a) 1 (b) 5	Topdressed
4	124 Ruahine silt loam	Browntop dominant, ryegrass, clover and mixed grasses	900–1,400	70 (with fogs & dews)	1–2	1½	Little top-dressing
5 (original farm)	25cH Tuatini silt loam & 122 Makara silt loam	Danthonia dominant, mixed grasses	below 300	45	1–2	1½	Little top-dressing

Managemental Factors

A number of managemental factors have been suggested as contributing to wear in sheep's teeth.

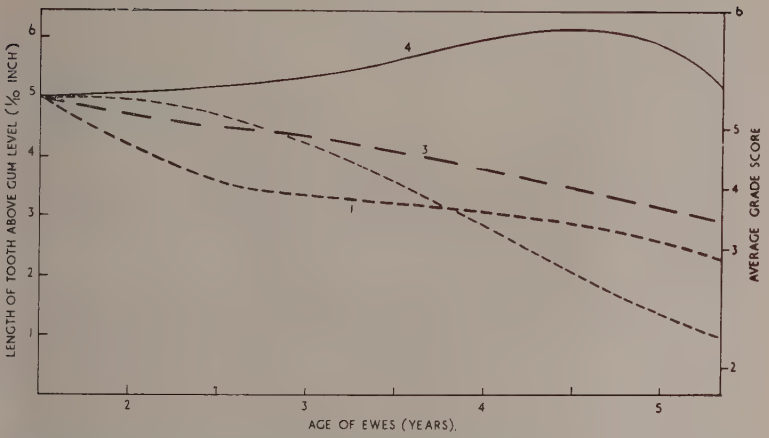

Fig. 17.—Graph showing relative rates of wear and growth (eruption) of central incisors (for details see Table 19).

No. 4. Little wear, and teeth continued to lengthen until the ewes were about 4 years old, after which the eruption rate appeared to decrease.

Nos. 1 and 2. Rates of wear exceeded eruption rates from the earliest stages.

Manurial Treatment

Continued topdressing is commonly blamed for the progressive deterioration in sheep's mouths. Since the improved grasses which permit the increased carrying capacity (with which is associated deterioration in quality of sheep's teeth) are the result of topdressing, it can, in this sense, be regarded as the cause of the trouble.

Comparisons were made between the effect of different manurial treatments on sheep's teeth. Ewes bought as 2-tooths were divided into five similar groups each of 20–25 ewes, and were maintained under "fat lamb" conditions at the rate of 6–7 ewes per acre for the next four years on similar pastures of perennial ryegrass and white clover. (These plots had been established for nine years and are described more fully by Clarke, Barton, and Wilson (1953)).

The manurial treatments were:

1 cwt. superphosphate annually.

4 cwt. superphosphate annually.

4 cwt. basic slag annually.

2 tons limestone initially, then 5 cwt. superphosphate plus 5 cwt. limestone annually.

Ditto, plus 2 cwt. 30% potash salts annually.

By means of reserve sheep and cattle, the experimental ewes were maintained under similar conditions of grazing. Analyses of variance of the final results gave no significant differences between the average lengths or grade scores of teeth of ewes from "fat-lamb" pastures manured by these widely different treatments. (As would be expected the average grade score was not high).

Results obtained in an earlier experiment with ewes carried to the 4-year stage (3 lactations) support this finding.

While deterioration in quality of sheep's mouths is associated with increased carrying capacity resulting from topdressing, it is apparent that widely different manurial treatments had no specific influence on the quality of sheep's teeth. It is of interest to record that on certain farms on naturally fertile country where carrying capacity has increased as a result of management but without the aid of topdressing, sheep's mouths have deteriorated to about the same extent as those on similar, topdressed, properties.

There is therefore no evidence that the chemical ingredients of the artificial manures applied to pasture cause defects in sheep's teeth responsible for their rapid deterioration.

Rate of Stocking

While gross overstocking leads to overgrazing and excessive wear of sheep's teeth, it is not generally realised that much less severe conditions of overstocking are also inimical to tooth quality.

Effect of Overstocking in the Early Stages. For this experiment over 100 2-tooth ewes from a large sheep station were ear-tagged and randomized into two groups and kept on heavily topdressed pastures of perennial ryegrass and white clover. The teeth of individual animals were recorded annually during the next four lambing seasons.

One group (high plane) was stocked at the rate of 5 ewes per acre, the other (low plane) at 7 ewes per acre during the first two lactations, after which both groups were combined and held at normal average rate for the property of 6 ewes per acre.

Results in Table 20 show that the influence of this degree of overstocking during part of the first two lactations was still evident in later seasons when the ewes were normally grazed. The liveweights of the ewes were also adversely affected.

TABLE 20. EFFECT OF OVERSTOCKING DURING FIRST AND SECOND LACTATIONS ON QUALITY OF EWES' TEETH AT LATER STAGES
(Av. length central incisor in tenths inch)

Age of ewe (months ± 1)	18	30	42	54	63
Initially on high plane					
5 ewes per acre	5.3	4.2	—	—	—
6 ewes per acre	—	—	3.9	3.9	2.9
Initially on low plane					
7 ewes per acre	5.0	3.8	—	—	—
6 ewes per acre	—	—	3.0	2.7	2.0

Results of experiments by Leslie (1938) and Coop and Clark (1955) are in accord with these observations.

Effect of Gross Overstocking under "Fat lamb" Conditions on Teeth of Cast-for-age Ewes. For this experiment, 5-year-old ewes were randomized into two groups and maintained from April to early October in their fifth lambing season on the pastures described in the foregoing section at different nutritional levels. As shown in Table 21 the effect on the teeth (and on ewe live-weight, wool, and milk yield) was drastic.

TABLE 21. EFFECT OF 50% OVERSTOCKING RATE ON TEETH OF 5-YEAR-OLD EWES ON "FAT LAMB" PASTURES

	Ewes per Acre	Tooth length in tenths of an inch		
		Before experiment	After experiment	Wear
Normal plane	6	3.1	2.4 ("Good one-year mouths")	0.7
Low plane (overstocking)	9	3.0	0.8 ("gummies")	2.2

Effect of "Controlled Rotational Grazing" on Sheep's Teeth. For this experiment the mouths of ear-tagged ewes maintained at the Te Awa Research Station, Grasslands Division, Department of Scientific and Industrial Research, were followed (Suckling, 1954).

Results showing comparisons of mouths of ewes bought as 2-tooths and kept for four years under different systems of management on the same property are recorded in Table 22. The difference in favour of the mouths of ewes from "controlled rotational-grazed" areas is striking and has been shown statistically to be highly significant.

TABLE 22. EFFECT OF GRAZING PRACTICES ON WEAR OF SHEEP'S TEETH

Method of Stocking	Ewes per Acre	No. of Ewes	Av. Length Central Incisors at 5½ years old (1/10 in.)	Ewe Live-weight (lb.)
Set stocking for 4 years	3	55	2.4	120
Controlled rotational grazing for 4 years	4½	55	3.9	125

It is evident that controlled rotational grazing ensures an even supply of medium-length, fresh, succulent, herbage, and reduces the prevalence of periods of feed shortage with consequent overgrazing. Grazing practices have subtle but important influences on the rate of wear of sheep's teeth.

Effect of "Cattling". It is commonly stated that heavy stocking with cattle maintains pasture in a fresh, succulent leafy state with consequent minimum wear of teeth of sheep maintained on them. Our rather limited observations support this theory.

TABLE 23 (a). HIGH-PRODUCTION GRASSES FROM TOPDRESSED PASTURES (FAT-LAMB COUNTRY) (Per cent of Dry Matter)

No.	Herbage Species		D.M. %	Crude Protein (N x 6.25)	Pure Protein	N.F.E. (by diff.)	Crude Fibre	Ether Extract	Ash	Ca	P	Ca : P
	Perennial ryegrass											
1	Highly topdressed pastures	Manawatu	—	31.4	24.7	30.8	19.5	7.3	11.0	0.40	0.46	0.9
2	do	do	—	23.2	17.6	35.0	25.9	5.6	10.0	—	—	—
3	do	do	20.4	28.5	—	39.2*	16.2	—	10.1	0.90	0.39	2.3
	White clover											
4		Manawatu	12.8	32.7	—	36.5*	16.3	—	8.9	0.99	0.40	2.5
5		do	—	31.9	—	—	9.0	—	—	1.00	0.39	2.5
	Red clover (Montgomery)											
6		Manawatu	13.7	32.0	—	41.8*	11.5	—	9.1	1.33	0.49	3.0

* Assuming 6% ether extract

TABLE 23 (b). MEDIUM-PRODUCTION GRASSES FROM TOPDRESSED PASTURES (FAT-LAMB AND EASY HILL COUNTRY) (Per cent of Dry Matter)

7	Cocksfoot	Manawatu	22.1	19.9	—	48.7*	15.6	—	10.8	0.50	0.30	1.3
8	Annual meadow grass	Manawatu	—	19.2	16.4	46.0	19.2	5.5	10.1	0.40	0.34	1.2
9		do	—	21.4	17.9	41.2	22.7	4.6	10.1	—	—	—
	Rough-stalked meadow grass											
10		Manawatu	—	23.9	21.2	37.3	18.9	7.1	12.8	0.40	0.43	0.9
11		do	—	21.8	18.3	33.3	25.5	6.7	12.6	—	—	—
12	Paspalum	Waiuku	—	16.4	—	48.0	21.3	4.3	10.0	1.00	0.27	3.8
13	Yorkshire fog	Manawatu	—	25.7	—	—	34.7	—	—	0.38	0.35	1.1
14	Browntop	Manawatu	—	19.8	—	—	17.2	—	—	0.27	0.28	1.0
15	Sweet vernal	Manawatu	—	25.7	—	—	16.1	—	—	0.39	0.25	1.6
16	Buffalo grass	Manakau Heads	—	18.5	14.8	35.8	29.9	5.3	10.5	0.26		—

* assuming 5.0% ether extract

TABLE 23 (c). NATIVE AND OTHER GRASSES FROM HILL COUNTRY AND OTHER LOW-FERTILITY REGIONS (SHEEP-BREEDING COUNTRY) (Per cent of Dry Matter)

	Danthonia										
17	Central Otago	—	7.0	—	50.4	32.8	2.7	7.1	0.30	0.24	1.3
18	Mangaweka	—	6.8	—	50.0	32.9	0.6	9.7	0.38	0.11	3.5
19	Moutere Hills, Nelson	—	6.4	5.6	51.9	27.1	4.9	9.7	0.11	0.15	0.7
	Browntop										
20	Nelson	—	9.7	4.5	46.3	31.5	4.1	8.4	0.41	0.39	1.0
21	Whangaehu R.	—	7.6	5.1	53.0	26.2	3.3	9.9	0.38	0.19	2.0
22	Ratstail Wanganui River	—	10.3	9.1	46.4	28.1	6.6	7.8	0.38	0.24	1.6
23	Chewings fescue Karioi Plains	—	10.9	10.4	40.6	29.2	10.0	9.2	—	—	—
24	Cocksfoot Central Otago	—	13.4	12.7	41.7	31.0	5.1	8.8	0.34	0.31	1.1
25*	Hard tussock Whangaehu R.	—	4.2	—	46.9	36.8	2.1	9.9	0.18	0.40	0.5

* excluded from average—apparently not grazed normally.

TABLE 23 (d). SCRUB AND WEEDS FROM HARDEST SHEEP-BREEDING HILL COUNTRY (Per cent of Dry Matter)

	Gorse tips (1–1½ in.)										
26	Young Moutere Hills, Nelson	—	28.4	—	22.4	38.9	4.3	6.0	0.39	0.33	1.2
27	Mature plant Awahuri, Manawatu	28.5	19.9	18.0	39.5	29.5	4.9	6.1	0.41	0.27	1.5
	Blackberry shoots and tips										
28	Manawatu	—	30.7	28.9	47.9	12.6	3.1	5.6	0.30	0.51	0.6
29	Lower Moutere, Nelson	30.6	19.5	18.9	60.5	11.4	2.8	4.3	0.35	0.35	1.0
	Bracken fronds (curled; under 6 in. high)										
30	Manawatu	14.1	25.3	—	52.6	10.7	2.3	9.1	0.18	0.51	0.3
31	Lower Moutere, Nelson	16.7	32.5	28.6	44.6	10.2	2.7	9.7	0.31	0.64	0.5
32	Bidi bidi (Hutuwai) Tokomaru, Manawatu	27.1	—	—	—	13.0	2.5	—	—	—	—

TABLE 24. Variations in Composition of Herbage at Different Stages of Growth (heavily topdressed pastures)
(Per cent of Dry Matter)

Herbage Species	D.M.%	Crude Protein (N x 6.25)	Pure Protein	N.F.E. (by diff.)	Crude Fibre	Ether Extract	Ash	Ca	P	Ca : P
Browntop										
9 Oct. 3 in. high (a)	16.2	36.9	—	—	17.3	—	11.5	0.46	0.63	0.7
21 Oct. 4 in. (b)	19.4	36.7	—	—	14.9	—	11.7	0.53	0.48	1.1
3 Nov. 6 in. (c)	21.6	29.9	—	—	17.3	—	10.2	0.43	0.39	1.1
after grazing, second growth										
28 Nov. 3 in. (d)	26.8	29.6	—	—	16.8	—	12.5	0.43	0.40	1.1
after grazing, third growth										
16 Dec. 3 in. (e)	26.0	27.9	—	—	20.5	—	9.5	0.45	0.44	1.0
Timothy										
21 Oct. 6 in. (a)	19.6	34.1	—	—	18.8	—	10.6	0.79	0.57	1.4
after grazing, second growth										
28 Nov. 5 in. (b)	24.2	25.7	—	—	18.3	—	10.7	0.57	0.42	1.3
after grazing, third growth										
16 Dec. 3 in. (c)	24.4	23.6	—	—	20.4	—	8.1	0.38	0.71	0.5
Cocksfoot										
9 Oct. 4 in. (a)	17.9	37.3	—	—	20.7	—	10.7	0.48	0.47	1.0
after grazing, second growth										
28 Nov. 4 in. (b)	24.3	23.4	—	—	18.6	—	13.0	0.51	0.39	1.3
after grazing, third growth										
16 Dec. 4 in. (c)	24.6	18.4	—	—	14.7	—	10.4	0.52	0.32	1.6

TABLE 25. AVERAGE COMPOSITION OF HERBAGE EATEN BY SHEEP UNDER DIFFERENT CONDITIONS OF FARMING (Per cent of Dry Matter)

	Approx. Stocking Rate (ewes/ ac.)	Typical Mouth (Row No. in Fig. 2)	Crude Protein (N x 6.25)	Ratio Poly-saccharides to Crude Protein	N.F.E. (by diff.)	Crude Fibre	Ether Extract	Ca	P	Ca : P
1. High-production perennial ryegrass and clovers from topdressed pastures	5–7	4	30.0	1.8	37.3	16.4	6.3	0.92	0.43	2.1
2. Medium-production grassses from topdressed fat-lamb "easy" hill country	2–4	2–4	21.2	3.0	39.8	22.1	5.4	0.45	0.33	1.4
3. Native grasses from hill country and other parts used for sheep-breeding	1–2	1–2	9.0	8.6	47.4	29.7	4.1	0.29	0.23	1.3
4. Weeds and scrub tips from "hardest" sheep-breeding hill country	below 1	1	26.5	2.4	45.3	18.0	3.2	0.32	0.43	0.7

Managemental factors relating to rate of stocking play an important part in determining quality in sheep's mouths. Some of the mysterious differences reported between teeth of sheep from flocks on otherwise similar properties doubtless arise through differences in managemental practices.

The effects of overgrazing, unless drastic, may not be evident from the rate of lamb growth since the milk yield of the ewe suffers less than other factors through food restriction. The effects on teeth, wool yield, and ewe liveweight would not be recognized, however, unless individual records were kept. Moreover, the effects on ewe liveweights would have disappeared by weaning or drafting for ewe fairs, and ewes previously underfed would not usually appear at a marked disadvantage alongside others.

A reduction in carrying capacity, heavier "cattling", adoption of modified grazing methods such as "controlled grazing" (Suckling, 1954) and early weaning (Barnicoat, Murray, Roberts, and Wilson, 1956) would, among other advantages, effect considerable improvement in the quality of the teeth of sheep on topdressed country.

Nutritional Factors

The type of abnormal wear under consideration is not primarily the result of abrasion caused by such substances as dust, silt, worm casts, sand, schist, small stones, etc. It would appear rather to be due to the replacement of the original sheep feed, principally the finer native grasses, by high-yielding European grasses maintained by topdressing with artificial manures. The consumption of the herbage of improved pastures by sheep could conceivably affect certain feeding habits in a manner which would be detrimental to tooth quality.

Overgrazing

It has been shown that overgrazing caused by overstocking causes excessive wear of sheep's teeth. Low grazing on to the soil, or leaves splashed with soil does not appear to cause excessive wear however (Part 4). The fibrous crown, particularly of dried-up pastures, is more likely to be responsible.

Certain grasses found on medium fertility soils, in particular crested dogstail and ratstail, appear to be tough, particularly under dry conditions, and are considered by experienced farmers to cause excessive wear in sheep's teeth in districts in which they predominate. Toughness of the feedstuff does not by itself promote wear, since sheep fed tough stalky hay or chaff (with concentrates) under winter-feeding conditions overseas, or for experimental purposes, retain long teeth. Wear occurs only in mouths of sheep obtaining their food by grazing, through the mechanical effects of nipping and pulling the herbage from the growing plant.

Excessive Eating

Heavy ewes consume as much as 50% more food than light animals of similar age and frame and the extra biting would contribute to the wear of the teeth.

Cud Chewing

Products of rumen fermentation are chemically similar to those in actively growing herbage. Studies on the effects of rumen fluid on teeth are in progress.

Chemical Composition of Herbage in relation to Wear

Chemical analyses of leafy portions of native and European pasture species at various stages of growth, and of edible portions of certain shrubs and weeds browsed by sheep were made from samples plucked at "sheep-grazed" height.

Results are shown in Tables 23 (a-d) and 24, and are summarized in Table 25.

It is evident that the chemical composition of the herbage ingested by sheep varies greatly. Pastures used for fat-lamb production (dominant perennial ryegrass and white clover) are rich in protein, calcium, and phosphorus (Table 23a) and the proportions of these nutrients decrease as the productivity of the pasture species declines (Tables 23b, and c). The polysaccharide : protein ratio increases greatly, but the Ca : P ratio remains about the same. This direct relationship between nutritive value of pasture and extent of wear in sheep's teeth is, however, only apparent. Sheep grazing on weeds and scrub (Table 23d) retain excellent teeth, at least under North Island conditions, yet the chemical composition of the edible portions resembles that of the most highly productive pastures (Tables 23a) which are responsible for the poorest teeth. This similarity in composition is merely due to the fact that in both cases the samples comprise the young leafy portions of the plants.

Results recorded by other workers are also of interest. Sears *et al.* (1948) obtained the following results from mixed pastures of the "fat lamb" type in the Manawatu district, with clover : ryegrass ratios ranging from 0.7 : 1 to 9.0 : 1 (35 analyses).

	Per cent of Dry Matter	
	Range	Average
Protein (N x 6.25)	19.7–33.3	27.6
Ca	0.47–1.24	0.76
P	0.26–0.68	0.42
Ca : P	—	1.8

These are similar to the results in Table 23a. Coop *et al.*, (1953) obtained the following results from 18 South Island hill pastures;

	Per cent of Dry Matter	
	Av. Spring	Av. Summer
Protein (N x 6.25)	13.8	7.9
Ca	0.44	0.29
P	0.23	0.12
Ca : P	1.5	1.9

Browntop from the same area varied widely in composition according to season :

	Per cent of Dry Matter		
	Av. Spring	Av. Summer	Av. Winter
Protein (N x 6.25)	13.6	7.0	3.3
Crude fibre	21.4	28.2	28.0
Ca	0.38	0.20	0.20
P	0.19	0.11	0.04
Ca : P	2.0	1.8	5.0

These analyses of browntop from rather poor hill country are comparable with North Island values of samples from similar country (Table 23c), and are altogether poorer in composition and nutritive value than browntop grown with the aid of topdressing (Tables 23b and 24). Browntop from topdressed pastures is in fact similar in composition to ryegrass.

Teeth of sheep on tussock country do not, as a rule, wear to any extent since these animals do not normally eat the tough tussock, as was formerly supposed, but rather the succulent weeds growing amongst it (Coop *et al.*, 1953). These workers showed that certain edible weeds, e.g. hawkbit and catsear, are valuable foods for sheep. Sheep in tussock country of the North Island and in the Nelson district frequently retain chisel mouths. In the main ranges of the South Island, however, the lower rainfall causes dry conditions which permit the distribution by wind of fine river silt and glacial loess, the abrasive effect of which accounts for the shorter teeth of sheep in that area.

From a consideration of the foregoing tables of composition of herbage eaten by sheep it is concluded that

(a) Sheep's teeth wear down rapidly on highly improved pastures of perennial ryegrass and white clover.

(b) On medium-fertility grasses and clovers and short-rotation ryegrass (Italian × perennial) sheep retain fairly good mouths.

(c) On native grasses, particularly in the North Island, sheep's teeth wear very little.

(d) On scrub and tussock country, where food is usually scarce and consists chiefly of succulent weeds and growing tips of shrubs, sheep's teeth are excellent and sometimes remain unworn (chisel-mouthed).

Herbage contains organic compounds—hydroxy acids, amino acids, and phosphorylated products of carbohydrate metabolism—capable of dissolving (complexing) the calcium of the insoluble calcium phosphate which constitutes the hard inorganic structure of the tooth. As far as is known these substances are present in highest concentration in the most actively growing tissues, and would therefore be present in highest concentration in young leaves of the highly productive improved ryegrass and clovers. Their erosive action on the hard inorganic matter of the tooth would be reinforced by the abrasive action of the fibre of the grass. This theory of their joint action would account satisfactorily for the type of wear under investigation and a considerable amount of work has already been carried out in this laboratory to test this hypothesis, but the experimental difficuties are formidable. Work is proceeding and the results will be reported elsewhere.

Seasonal Influences on the Rate of Wear of Sheep's Teeth

Rates of wear of central incisors were determined from measurements of the distance of the biting edge of the tooth to a fixed mark (file nick), by means of wax impressions. The ewes were grazing heavily topdressed pastures of perennial ryegrass and white clover, in an area with a well distributed rainfall. In Table 26 it is seen that twice as much wear occurred in spring as in any other season.

TABLE 26. RATE OF WEAR OF SHEEP'S CENTRAL INCISORS
(Average from 34 ewes for 3 successive years)

	August–October	November–January	February–April	May–July	Total
	Spring	Summer	Autumn	Winter	
Wear (1/10 in.)	1.91	0.80	0.91	0.80	4.42
% of total wear	43	18	21	18	100

While wear was continuous, it was most pronounced in spring when the nutritional demands of ewes are at a maximum for milk production and regeneration of body tissues after gestation and parturition. These extra nutritional demands are met by the extra consumption of the readily available spring flush of growth of pasture.

Minerals

Calcium and Phosphorus. Since about 90% of the tooth (air dry) is calcium phosphate, the content of calcium and phosphorus in the herbage eaten is of considerable interest to this investigation. It has

been shown by Fitch (1943) and by Ewer and Bartrum (1948) that under certain conditions in New Zealand calcification of bones of sheep is impaired and that rickets sometimes ensues. These workers showed that while the calcium and phosphorus contents of the herbage tended to be low, the limiting factor was vitamin D. No deleterious effects on teeth were associated with the impaired calcification of the bones, however, which is in keeping with the general finding that teeth are less affected by nutritional disturbances than bones, except in the early, formative stages.

Franklin (1950) on the other hand, found that diets deficient in calcium and phosphorus had very adverse effects on teeth of sheep maintained on them. He fed cereal roughages and grains, or their by-products, their mineral composition being (dry-matter basis):

Calcium	0.05 to 0.11%
Phosphorus	0.14 to 0.40%
Ca : P	1.2 to 3.9

and all proved unsatisfactory, causing a general stunting of the whole skeletal structure, irregularities and gaps in the molar teeth, delayed eruption of the permanent teeth, and a tendency to overshot conformation. (These symptoms are similar to fluorosis). When 1% calcium carbonate was added to the diet during the critical early stages of dental development, the teeth were usually normal. This problem was not one of attrition since the incisors of aged ewes remained practically unworn.

Accepted standards for minimum requirements of calcium and phosphorus for sheep are recorded in Table 27.

TABLE 27. MINIMUM ADEQUATE REQUIREMENTS OF CALCIUM AND PHOSPHORUS FOR SHEEP

	Mitchell (1947) (% Dry Matter)		U.S. Nat. Res. Council (1949) (% Dry Matter)	
	Ca	P	Ca	P
Growing lambs	0.18	0.15		
Ewes			0.20 - 0.33*	0.18 - 0.24*
Ca : P	1.2		1.2 – 1.6	

* higher values are for ewes in lactation.

The intakes of calcium and phosphorus by grazing sheep in New Zealand show wide differences. Coop *et al.* (1953) consider that while the minimum levels are reached at times in pastures of the South Island hills, their concentrations of minerals over the whole year are probably adequate. Ewer and Bartrum (1948) found 0.37% of calcium and of phosphorus in the dry matter of Italian ryegrass on which hoggets had developed rickets. These values (Ca : P ratio 1.0) are considerably higher than the estimated minimum (Table 27). This subject is most complex, especially since Grant (1953) has postulated the presence of anti-calcifying agents in young grass.

It is evident from Tables 23–25 that the poorest and most worn teeth were usually associated with pastures richest in calcium and phosphorus and vice versa, although really low levels of these elements were not found in any samples of North Island herbage analysed.

There is as yet no evidence to suggest that a simple calcium or phosphorus deficiency, excess, or imbalance is responsible for deterioration in quality of sheep's teeth. (Laboratory studies on this aspect of the problem are proceeding).

Other Inorganic Elements. Variations in quality of sheep's teeth from different parts of New Zealand are not related to any deficiencies or nutritional imbalances of trace elements (i.e. iodine, copper, molybdenum, cobalt, iron, fluorine*) nor can they be correlated with the geological formation or with soil type. There is no evidence to suggest that mineral deficiencies cause weaknesses in sheep's teeth. Experiments with sheep from pastures maintained under highly contrasting systems of manurial treatment (Part 4) likewise gave no indication that inorganic substances influence the quality of sheep's teeth.

Fibre Content of Feedstuffs

Toughness of pastures is undoubtedly a factor contributing to wear in teeth; nevertheless the crude fibre content of herbage as determined by the Henneberg method, is not related to the extent of wear (Tables 23–25).

Vitamins

Vitamin D. The vitamin D status of the diet is of practical importance to sheep-feeding practice in New Zealand (Leslie, 1935). The content of Vitamin D in the young, high-producing pastures on which sheep's teeth wear most rapidly may be deficient through two causes: (a) such pastures are kept short and succulent and animals consuming them ingest very little sun-dried roughage—stalks and seed heads—which, like sun-cured hay, are good sources of vitamin D. (Vitamin D is derived from the precursor ergosterol by the action of ultra-violet radiation of the sunlight); and (b) evidence has been adduced by Grant (1953) that young grasses contain an anti-vitamin-D substance, the yellow fat-soluble pigment carotene, the precursor of vitamin A, which is present in relatively great amounts (0.05–0.08% dry matter) in New Zealand pastures of perennial ryegrass and white clover (Dr. W. A. McGillivray, pers. comm.). The efficient utilization of fat-soluble vitamins is also dependent on the antioxidant properties of vitamin E—α tocopherol—which is lower in clover-rich pastures (McGillivray, 1952; N. A. Worker, pers. comm. 1956).

Three experiments involving more than 250 sheep have been carried out to determine whether vitamin D is concerned in the calcification and development of sheep's teeth.

In Experiment 1, one lamb of each set of twins from 20 ewes was drenched at weekly intervals at the rate of 500 units D_2 per day from 6 months until 18 months of age.

* Results of our work on the fluorine content of sheep's teeth will be published later.

In Experiment 2, ewe hoggets were injected subcutaneously before winter with one million units D_2 in oil.

In Experiment 3, ewe hoggets were injected with D_2 before winter for 3 consecutive years at the rate of one million units per animal.

The results are summarized in Table 28.

TABLE 28. RESULTS OF EXPERIMENTS WITH VITAMIN D
(Animals maintained under "fat lamb" conditions)

Experiment 1	Dosed (20)	Controls (20)
15 months of age		
Av. no. of teeth cut	1.4	1.4
18 months of age		
Av. length perm. incisors (1/10 in.)	4.9	4.9
Av. total length enamel crown (1/10 in.)	0.91	0.92
Av. wt. air-dry incisor (g.)	0.98	0.98
Bones: Av. breaking strain of metacarpals (lb.)	103 (96–113)	102 (85–118)
Wool: Av. wt. 15 months (lb.)	11.3	11.9
Liveweight: Av. at 18 months (lb.)	84	80
Experiment 2	Dosed (45–50)	Controls (45–50)
21 months of age		
Av. liveweight (lb.)	124	123
Av. no. of teeth cut	2.6	2.4
Av. length perm. central incisors (1/10 in.)	4.5	4.4
3 years of age		
Av. length central incisors (1/10 in.)	3.7	3.8
Experiment 3	Dosed (55–60)	Controls (55–60)
11 months of age		
(only deciduous teeth showing)	—	—
21 months of age		
Av. no. teeth cut	2.5	2.5
Av. length central incisors (1/10 in.)	4.4	4.4
33 months of age		
Av. no. teeth cut	6.0	5.9
Av. length central incisors (1/10 in.)	4.6	4.5
45 months of age (full mouthed ewes)		
Av. length central incisors (1/10 in.)	4.2	3.9
54 months of age		
Av. length central incisors (1/10 in.)	3.5	3.3

There were no significant differences between dosed ewes and controls.

No improvement in quality of mouths of growing sheep liberally grazed on improved pastures notable for causing tooth wear was effected by means of additional vitamin D.

Since the concentration of vitamin D in the tissues of sheep is in part due to the action of ultra-violet light on the precursor ergosterol, derived from the food and distributed in the subcutaneous tissues, comparisons were made in 1950 between the teeth of 4-year-old sheep with woolly coverings on the face and legs and "open-faced" animals. No differences whatever could be detected in the averaged data concerning characteristics of the teeth of the two groups. This is of interest because, more recently, considerable attention has been devoted to studying differences in other productive qualities between ewes of these two types. (Barton, 1954; Coop, 1956).

Other Vitamins. As discussed earlier, vitamin A in the form of its precursor carotene is present in ample amounts in pasture herbage even when dried up. Lack of water-soluble vitamins is never a problem with ruminants since they are provided plentifully by the symbiotic rumen microflora. A deficiency of vitamin C (ascorbic acid) has never been reported in ruminants.

There is therefore no evidence to support the rather popular theory that deterioration in the quality of sheep's teeth results from nutritional deficiencies—minerals, vitamins or both—in the herbage of the high-yielding pastures.

Part 5. Hereditary Characteristics in Sheep's Mouths

Many farmers consider that the quality of sheep's mouths is primarily determined by heredity and, as a consequence, mouths of sheep of different breeds or of different strains or even flocks in one breed will exhibit considerable and distinctive variations. However, a number of factors, environmental and others, can alter conditions and modify the mouths and their eventual qualities and soundness.

Modifying Influence of Environmental and Managemental Factors

The changeover experiment summarized in Table 19 demonstrated very clearly that groups of ewes from a large flock after being transferred for 3½ to 4 years to four other properties developed mouths indistinguishable from those of the ewes bred on them. Moreover, the properties were within a radius of only 10 miles of one another, yet the final appearances of the mouths were as varied as those encountered in sheep throughout the whole of New Zealand.

On the other hand, it has been shown, particularly in Part 3 Tables 13 and 16 that in certain flocks the mouths are characterized by the prevalence of some particular fault and, as a result, it is not unusual to find a flock that is exceptional with regard to tooth quality within an otherwise well-defined region.

This interesting practical finding is, however, not at variance with results that emphasize the importance of heredity. By further consideration of the factors causing variations in quality in mouths of sheep on different classes of country these two points of view can readily be reconciled.

Variation between Mouths of Different Breeds

Since this investigation was purposely restricted to a study of teeth of the Romney ewe, the adverse criticism levelled at this breed in this publication must not be taken as implying that this breed has any particular or pronounced weakness not found in others.

Most farmers consider that the mouths of the fine-woolled breeds are superior to those of the strong-woolled breeds. Teeth of Merino ewes are somewhat different in appearance from those of other breeds, tending to be rectangular in cross-section with a close, compact appearance. The statement that they last better is possibly of traditional origin, being based on early experience when the country was unimproved and thinly stocked. With the introduction of European grasses and topdressing, Romneys have replaced Merinos, and comparisons are not practicable.

In parts of the South Island and in Tasmania, however, Corriedales and other breeds with a Merino foundation do not appear to have better mouths than Romneys when farmed under similar conditions.

Opinions of farmers and stock agents on the comparative qualities and durability of mouths of Romneys and Romneys crossed with various other breeds, particularly Lincolns and Ryelands, are contradictory. Results of inspections made in the course of this investigation of mouths of Southdowns (rams) and of a limited number of flocks of Cheviots and various Cheviot-Romney crosses, Lincolns, and Ryelands, indicated that the types of defects are similar in nature, and their incidence of the same order. An impression remains that the Romney mouths were at least as good as those of other breeds farmed under similar conditions.

Variations in Mouths between Romney Flocks

It is commonly stated that distinctive types of mouth are associated with different flocks of Romney sheep. Results in Part 2, particularly Table 13, confirm the opinion that district differences in mouths due to a prevalence of certain faults are typical of certain flocks, and that a high grading for tooth quality is determined chiefly by the absence of these defects.

Latent Faults in Sheep's Mouths

The apparent discrepancy between the observations that the soundness and durability of sheep's mouths are influenced (a) by environmental and managemental factors and (b) by inherent qualities in the sheep is explained by the finding that the defects only became objectionable in mouths of animals under intensive conditions of grazing on improved pastures, and were of little importance in sheep maintained on unimproved country (native grass and scrub) on which teeth normally wear very little.

Faults in sheep's mouths are latent, and develop in accordance with the type of feeding to which the sheep is subjected. This finding is illustrated by results in Table 19, further details of which are presented in Table 29.

It is seen that mouths on the property where least wear has occurred (No. 4) have a tendency to be slightly overshot, but as feed was some-

TABLE 29. MODIFYING INFLUENCE OF 4 DIFFERENT PROPERTIES ON DEFECTS DEVELOPING IN MOUTHS OF SHEEP DERIVED FROM ONE FLOCK (after $3\frac{1}{2}$ years)

Property No.	Final No. of Sheep Observed	Av. Length Central Incisors at 5 Years of Age ($\frac{1}{10}$ in.)	Approx. Percentages of Defects in Mouths Apparent at 5 Years of Age				
			Undershot			Slightly Overshot	"Gummy"
			Slight (Below $\frac{1}{16}$ in.)	$\frac{1}{8}$ in. and more	Total Incidence		
1	16	1.4	31	31	62	none	31
2	99	2.3	15	13	28	7	none
3	33	2.9	21	15	36	none	none
4	22	5.1	9	none	9	5 (+27)*	none

* Very slightly "eaten out in front", typical of slightly overshot jaws (Fig. 7) but long, fairly close teeth of good quality.

times short, the effect of occasional periods of overgrazing on pastures, comprising browntop and mixed grasses under fairly high rainfall conditions, was merely to cause slight wear of the front incisors. On the 3 other properties teeth show effects of excessive wear and (as recorded also in Table 16) the mouths of group 4 with the lowest grade score were those with narrow teeth and tendencies to develop an undershot conformation.

In the following section the nature and course of development of the principal faults in mouths of the New Zealand Romney ewe of commercial disadvantage to the sheepfarming industry are considered in some detail.

COURSE OF DEVELOPMENT OF FAULTS IN MOUTHS OF ROMNEY EWES

Undershot Mouths (short lower jaw)

These mouths wear fairly quickly, the teeth developing a characteristic levelled appearance (Fig. 6). The prevalence of mouths with this defect in certain flocks (Tables 13 and 29) and the modifying influence of the environment has been discussed. Usually the defect became more pronounced as the animal matured, but in some cases a slightly undershot condition (below about $\frac{1}{8}$ in.) in sheep at the 2-tooth stage, about 18 months of age, improved. Such an improvement in early milder cases has also been observed previously, by American workers (Nordby *et al.*, 1945). It is not until the teeth have been cut for some time that the alignment of the central pair of incisors in relation to the upper pad becomes fixed, and the development and eruption of the contiguous incisors of the 4-tooth stage probably delays this further. Difficulties in detecting undershot mouths at the earliest stages for culling are probably due to these causes. The incipient undershot conformation can be detected with much more certainty at the 2-year-old stage, i.e. after the first lambing.

Davies (1949) remarks that "the high incidence of defects of the lower jaw in the sheep is well known, but the condition is still unexplained". The undershot condition is very strongly inherited. Nordby *et al.* (1945), as a result of 7 years' work, have concluded that sheep with this type of defect had longer skulls and shorter mandibles than the normal animal. Results of their preliminary experiments suggested a simple recessive inheritance of this defect, a hypothesis that was refuted by later experiments. They concluded that several pairs of genes, both dominant and recessive and acting on development of the mandible as well as on the skull, were involved.

Overshot Conformation

The course of development of overshot jaws is illustrated in Fig. 7. Donald and Wiener (1954) have reviewed the literature of this subject, chiefly as it concerns cattle. They conclude that, in cattle, single genes can bring out inequalities, but that, in addition to hereditary effects on the development of the bones of the skull and mandible, the influence of foetal and post-natal malnutrition may also be involved.

Franklin (1950) observed a tendency for sheep to develop overshot jaws on diets deficient in calcium. During the course of the present investigation the development of overshot jaws was observed in hoggets grazing on improved pastures with rampant clover growth promoted by warm, moist conditions in summer; and the tendency for this defect to develop slightly in ewes grazing on sparse pastures of the type normally causing minimum wear has already been described (Table 29).

Slightly overshot mouths tend to last well but the teeth become jagged with wear and when fully erupted usually wear down with a characteristic appearance—"eaten down in front", good examples of which are shown in Figs. 7A, 7B.

Small Teeth

It was assumed at an early stage of this study that, other things being equal, smaller teeth would wear out more rapidly than large ones. This theory has been amply borne out by subsequent results (Tables 1 and 17), and it has also been shown that teeth vary greatly in their initial size (Fig. 1 and Tables 5–7), i.e. in their potential "lasting quality". In Figs. 8, 9, 10, 11, 12, differences in rate of wear of narrow and of wide teeth of sheep reared under identical conditions are shown.

Overlapping Central Incisors, Leading to Development of a Deep "V"

An unsightly "V" nick between the central pair of incisors can be found in sheep in most flocks, and in some areas the fault is widespread. The defect is associated with a narrow overcrowded jaw and the nature of its occurrence and frequency in certain flocks suggests that it is of hereditary origin. The deep, unsightly Vs could usually be traced, by means of suitable records or photographs, to an overlapping of the central pair in their initial stages (Fig. 13). The overlap must have been present before the teeth erupted, probably at the foetal stage, for the defect is structural (Fig. 5). The defect was often particularly difficult to detect unless seen from above. The thin rebated portions

of the teeth were worn down rapidly, presumably by the tearing action of the fibre of such grasses as perennial rye.

Splayed Central Incisors, Changing to "Pointing" (i.e. inward-sloping centrals) and to Shallow Vs

Central incisors set in this manner, when first cut, may give a desirable but deceptive appearance of width, which changes later to the splayed appearance (Fig. 14). There was often a slight V between them at this stage, not due to wear but to their excessive curvatures outwards. As the teeth wear and erupt they finally assume a state of "pointing" and sometimes the edges wear further to give a shallow V.

Cleft Palate (Fig. 15)

This is usually associated with a slight undershot condition. Butz *et al.* (1942) consider the fault to be of hereditary origin.

"Spike Teeth"

These result from the effect of wear on teeth in an excessively wide jaw. A typical mouth of a ewe with this type of jaw is shown in Fig. 12. As pointed out in Part 3, this defect does not arise through the spreading of the teeth. This type of mouth would be disadvantageous only when food is scarce. It shows that a broad muzzle does not necessarily indicate a good mouth.

Wear in Deciduous Teeth

Except in the case of mouths with gross defects, differences in the extent of wear of the milk teeth of lambs gave no indication of the quality and soundness of the permanent set.

CHARACTERISTICS OF SOUND MOUTHS

It was inferred early in the course of this investigation that mouths free from the foregoing defects would be of better quality than the average, and such indeed was found to be the case (Tables 13, 14, 15, and 16; Figs. 8 and 9) even with sheep on highly improved pastures on which mouths wear badly.

Desirable characteristics in sheep's mouths are therefore:

(1) wide teeth, regularly and closely spaced.

(2) parallel-sided teeth indicating size and solidity both above and below the gum line.

(3) freedom from the tendencies to undershot and overshot conformation.

SUGGESTIONS FOR IMPROVING QUALITY OF SHEEP'S TEETH

The present poor state of sheep's mouths on many farms is, it is contended, due to lack of attention on the part of the owners to the quality of mouths of ewes retained, and more particularly of the flock rams introduced for breeding purposes. To keep pace with the improvements in carrying capacity, sheep with desirable productive qualities (meat and wool yields) have been bred, but little attention has been

paid by many farmers to the state of the teeth, particularly those of the rams. Hereditary characteristics of mouths and teeth are apparently contributed to equally by both parents. Each ram therefore influences the quality of mouths to the same extent as 40 or 50 ewes.

While it would not be practicable to cull all ewes with tendencies to faults in their mouths it is contended that the degree of selection at present is not nearly stringent enough.

Although the genetics relating to jaws and teeth of sheep are not yet understood, it is reasonable to assume that by selecting the breeding stock and eliminating undesirable animals, the average quality of mouths in a flock could be raised.

The types of teeth that are retained longest on improved pastures have already been described. It is therefore suggested that careful attention be paid to teeth when selecting sheep for breeding purposes. (It is easier to differentiate the faulty mouths at the early stages; the outstandingly good mouths come into prominence at later stages). Mouths of all animals should be opened and carefully inspected. The alignment of the lower jaw and the pad should be tested by feeling while the animal's head is in a normal unstrained position.

Ewes. A careful selection should be made at the 2-tooth stage (before the first mating season) and again at the 4-tooth stage, about a year later, when sorting the annual draft.

Rams. As is also the case with ewes, mouths of rams do not assume their permanent characteristics until the animals are at the 4-tooth stage. Gross faults will, however, be evident in younger animals. An inspection of mouths of older sheep of the stud from which the ram is being bought, particularly of those of sheep most closely related to the animal under consideration, would give some indication of its potentialities in this respect. Grosser faults such as a general tendency to undershot jaws, should be evident even from a simple inspection.

It is considered that an important factor in arresting the deterioration in quality of sheep's mouths taking place in flocks on improved country is a more careful attention to the hereditary aspects of the problem as outlined in this publication. Unless a determined effort is made along these lines the position will deteriorate even further, especially as much of the hill country at present carrying sheep with sound 5-year-old mouths is entering the category of improved pasture, chiefly through the agency of aerial topdressing.

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APPENDIX 1

Botanical Names of Plants Referred to in this Paper

Annual meadow grass	*Poa annua*
Bidi-bidi (piri-piri, hutuwai)	*Acaena* spp.
Blackberry	*Rubus fruticosus*
Bracken	*Pteridium esculentum*
Browntop	*Agrostis tenuis*
Buffalo grass	*Stenotaphrum secundatum*
Catsear	*Hypochaeris radicata*
Chewing's fescue	*Festuca rubra* subsp. *commutata*
Crested dogstail	*Cynosurus cristatus*
Danthonia	*Danthonia pilosa*
Gorse	*Ulex europaeus*
Hard tussock	*Festuca novae-zelandiae*
Hawkbit	*Leontodon hispidus*
Paspalum	*Paspalum dilatatum*
Perennial ryegrass	*Lolium perenne*
Ratstail	*Sporobolus capensis*
Red clover	*Trifolium pratense*
Rough-stalked meadow grass	*Poa trivialis*
Sweet vernal	*Anthoxanthum odoratum*
Timothy	*Phleum pratense*
White clover	*Trifolium repens*
Yorkshire fog	*Holcus lanatus*

OVIPOSITION PREFERENCE BY *Costelytra zealandica* (White)

By J. M. Kelsey, Entomology Division, Department of Scientific and Industrial Research, Ashburton

(*Received for publication, 27 November 1956*)

Summary

Data from artificially infested plots indicate that the common grass-grub beetle will lay very few eggs in land almost free from vegetable matter, but will oviposit to some extent in cultivated land growing rape. There was a highly significant preference, however, for land covered with pasture, though there were no significant differences in preference between dense or sparse tall or short pasture cover.

Introduction

This paper describes a small experiment designed to secure exact data on a subject that is of major importance to the farming community, and is based on a technique which takes into consideration known factors influencing behaviour of adult beetles and larvae. The beetles' habits are a matter of vital importance when making control recommendations.

The objects of the experiment were:

1. To secure information as to what types of pasture are likely to be selected for egg-laying by the above beetle.

2. To assist in developing an exact technique for testing effectiveness of insecticides used in grass-grub control.

Technique

The experiment consisted of an area 10 ft. × 9 ft. divided into foot-square plots by means of a thin cement and sand slurry run into the soil to a depth of 6 in., and finished flush with the soil surface so that beetles would have unhindered access to any part of the area. A spade was used to cut the crevices into which the slurry was poured. Barriers of cement and sand were found to be better than those made of wood or sheet iron because fungal hyphae from the former, and rust from the latter, adversely affected plant growth and larval activity in the vicinity of plot margins.

Previous tests had shown that the above technique gave the required depth of barrier to prevent larval migration from plot to plot, and that cross walls bonded well with those previously poured. Observations had shown also that, in the soil in question, beetles laid eggs at a soil depth not exceeding 5 in. Since eggs are often difficult to detect owing to the presence of soil particles adhering to them, and since first instar larvae are very small, it was decided to evaluate the trial when larvae were in the second instar. The possibility of larval mortality in plots from which plant roots were removed by sieving was not considered to be a factor of major importance, since it was possible for larvae emerging from eggs laid in such soil to produce apparently normal adults. The reason for this was that though most of the plant matter was removed by sieving, a great deal of smaller plant fragments remained in the humus. There is a possibility, however, that a certain amount of cannibalism

would occur in sieved plots if larval populations were very high. This could affect validity of results on such plots, and necessitates this point being investigated more fully.

The type of cover on the plots was defined as follows:

1. Rape. Ground completely covered by rape.
2. Minus roots and top. Soil sieved through $\frac{1}{16}$-in. mesh to remove vegetable matter.
   (a) Surface tamped hard.
   (b) Soil left as in fallowed unrolled ground.
3. Roots minus top. Aerial portion of pasture skimmed off with a sharp spade.
   (a) Surface tamped hard.
   (b) Plots dug and left reasonably fine and open as in fallowed unrolled ground.
4. Straw.
   (a) On bare ground, aerial portion of pasture skimmed off.
   (b) On pasture cut close to ground.
5. Pasture close grazed. Pasture cut close to ground.
   (a) 10% ground cover.
   (b) 25% ground cover.
   (c) 50% ground cover.
   (d) 100% ground cover.
6. Pasture 3 in. long.
   (a) 10% ground cover.
   (b) 25% ground cover.
   (c) 100% ground cover.
7. Pasture 6 in. long.
   (a) 10% ground cover.
   (b) 25% ground cover.
   (c) 100% ground cover.

There were 5 replicates of each type of cover, and plots were randomized within the block. Plant cover was then conditioned by hand; the final clips being made on 16 and 28 November 1951. The experimental block was enclosed by a wood and wire-gauze frame to prevent beetles flying off the area. Eight hundred and fifty mating pairs of beetles were collected over a period of 25 days, and placed in the enclosure, the period of collection being 17 November to 12 December 1951. Plots were dug up and examined for larvae on 10–12 April 1952, the soil from each foot-square six inches deep being placed on a sack to avoid loss of larvae that could otherwise crawl into vegetation.

Results

The following table gives numbers of larvae found in each replicate, and the totals for each type of cover:—

	Type of Cover	No. Larvae per Foot-square Plot	Total Larvae in 5 Plots
1	Rape; 100% cover	1, 16, 12, 13, 18	60
2a	Minus roots & top; ground hard	0, 0, 0, 0, 6	6
b	Minus roots & top; ground open	0, 1, 0, 1, 7	9
3a	Roots minus top; ground hard	2, 4, 0, 6, 34	46
b	Roots minus top; ground open	4, 16, 8, 6, 12	46
4a	Straw on bare ground	2, 15, 11, 15, 32	75
b	Straw on grazed pasture	25, 34, 24, 50, 65	198
5a	Close-grazed: 10% cover	33, 22, 23, 71, 41	190
b	Close-grazed; 25% cover	6, 16, 23, 38, 52	135
c	Close-grazed: 50% cover	15, 23, 49, 25, 49	161
d	Close-grazed: 100% cover	20, 62, 41, 37, 44	204
6a	Pasture 3 in. long: 10% cover	10, 21, 43, 39, 45	158
b	Pasture 3 in. long: 25% cover	16, 65, 23, 50, 73	227
c	Pasture 3 in. long: 100% cover	22, 32, 46, 55, 30	185
7a	Pasture 6 in. long: 10% cover	25, 25, 44, 57, 37	188
b	Pasture 6 in. long: 25% cover	35, 14, 14, 40, 51	154
c	Pasture 6 in. long: 100% cover	10, 33, 70, 68, 36	217

It was obvious that plots with pasture cover (Nos. 4b-7c) had more grubs than the others, and it was decided that they should be analysed separately. The smaller counts (Nos. 1-4a) had a highly skew distribution, as also had the pasture plot counts. A transformation was accordingly applied to all counts. The counts were highest in the N.W. part of the block. As the five plots of each type of cover had been randomized over the whole area and not into replicates, a correction for east to west and north to south meridians was particularly necessary.

Statistical analysis of these results showed that *Costelytra zealandica* oviposition sites were as follows in descending order of preference:—

1. Plots with any growing pasture cover at all—tall or short; thick or thin, and with and without straw on the surface (plots 4b-7c)—all had highly significantly more grubs than other treatments.

2. There were no differences between the 100% rape series and straw on bare ground, but these two together (plots 1 and 4a) had highly significantly more grubs than those without top cover (plots 2a-3b).

3. Plots with roots but no top cover (plots 3a, b) had highly significantly more larvae than plots without roots or top cover (plots 2a, b).

4. There were no statistical differences between compacted and open ground; beetles apparently having no particular preference as regards compaction of soil.

DISCUSSION

There are three factors that could affect choice of oviposition sites within the enclosure; these are:—

1. Beetles that did fly would tend to concentrate round the sides of the cage.

2. When beetles fly in breezes under 10 m.p.h. they almost invariably fly up wind, which would cause concentration towards the windward sides in relation to prevailing winds.

3. Female beetles, unlike males, are negatively phototropic, and, though they fly after dusk, would be influenced by intensity of moonlight during the emergence, feeding, and oviposition periods, and one would expect to find greater numbers of eggs or larvae towards the west of the enclosure.

From the above results the inference is that if there is any growing cover at all on a paddock, beetles will continue to lay the majority of their eggs in those areas, and that it is only when ground is becoming really bare and depleted of vegetable matter, both above and below ground, that they will leave a particular plot and move to areas with better pasture cover. The results of these tests were sufficiently promising to warrant the technique being adopted for artificially infesting chemical control plots.

In general, field studies and sampling year by year tend to confirm these oviposition preference findings. Previous work (Kelsey, 1952) has shown that beetles do not fly (a) during rain; (b) if grass temperatures are low; and (c) if wind velocities are over 10 m.p.h. In this particular instance, meteorological records of the nearest recording station (1 mile distant) indicated that though wind velocities were suitable for flights on 34 days, that there were 24 days without rain, and that temperatures were favourable on 21 days, the combination of these three factors was such that flights could have taken place on only 8 of the 45 days of the critical emergence period. This means that with this particular set of climatic conditions the great majority of eggs would be laid in areas of emergence, and that very little migration from those sites would occur, and one would expect to get heavier grub damage in that area than in the previous year.

From the above data on pasture cover and meteorological conditions in relation to oviposition it would be possible to predict with reasonable accuracy the extent of grass-grub damage from year to year, but one would have to take into account also the effect on pasture growth of evaporation factors for each district throughout the period of larval activity from December to October.

The problem of infestation is complicated by farm management practices such as stock concentration, harvesting activities, and probably by irrigation during critical periods in beetle emergence from November to March. Such factors would tend to disturb egg-laying beetles. Again, the above relatively simple explanation does not account for the sudden disappearance of this insect from paddocks that have carried high grub populations for several years, and still have good pasture cover. The writer believes that the explanation in this case is that population reductions are due to insect predators such as asilid and carabid larvae, but more particularly to presence of the "milky disease" bacteria, and nematodes, particularly the *Mermis* species found by the writer in March 1946 and described by Hoy (1952). In one series of experiments in Ashburton, this *Mermis* species had increased in numbers year by year till it could be found in approximately every fifth soil sample, and the following year it was extremely difficult to find grass grubs in that area.

An interesting feature of this experiment on oviposition preferences was that when an imaginary line was run through the centre of the block from North to South, and those plots through which the line ran

were excluded it was found that there were more than twice as many larvae on the west of the line (1,310) as on the east (629). It is possible that this was caused by female beetles moving away from direction of moonlight incidence after they had finished feeding and were searching for oviposition sites. Further work is being carried out to determine the significance of this factor.

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INSECTS ATTACKING TUSSOCK

By J. M. Kelsey, Entomology Division, Department of Scientific and Industrial Research, Ashburton

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Summary

A list is given of 45 insects that feed on roots or aerial portions of native tussock species, and the relative importance of those insects is discussed in so far as they affect tussock deterioration.

Introduction

In this paper the tussocks referred to are *Festuca novae-zelandiae* Cockayne, *Poa caespitosa* Forst., and *P. colensoi* Hook. f. at altitudes ranging from 1,500 to 4,500 feet. Data are confined strictly to tussock itself, and do not include inter-tussock vegetation. Insect terminology is that of Hudson or Tillyard (1926).

Hudson (1928, 1934, 1939, 1950) shows that at the dates of publication of his work there were only nine insects—all larvae of Lepidoptera—known to feed on tussock; in addition, 22 further species of adult Lepidoptera were recorded as being common on tussock, and a further 47 species from native grasses in tussock-dominant zones. The term "native grasses" has been used apparently in some cases as a general name to include the above three tussock species also. Dick (1940) extended the list of insects definitely attacking tussock to include a species of *Odontria* feeding on roots, and the caterpillars of the three moths *Persectania ewingi* Westwd., *Leucania toroneura* Meyr., and *L. acontistis* Meyr. Healy (1945) recorded grass grubs and *P. ewingi* larvae as damaging tussock. Given (1952) lists 19 species of melolonthids as being found in "subalpine scrub and tussock" or "usually under grass or tussock".

The presence of adult Lepidoptera (which are usually nectar-feeders) or other insects on tussock does not necessarily mean that they or their leaf- or root-eating larvae feed on tussock, so there are authentic records of only 13 species of insects that definitely eat one or more of the three tussock species mentioned above, and a large number of tussock-zone moths and smaller numbers of Coleoptera whose larvae may be able to eat tussock.

Insects Recorded on Tussock

The following records and notes refer only to insects that were actually seen by the writer to feed on tussock, or which contained tussock leaf fragments on dissection. The list of insects is as follows:

I. Leaf-eating species:

Agrotis ypsilon Rott.	(Noctuidae)
Argyrophenga antipodum Dbld.	(Nymphalidae)
Crambus flexuosellus Dbld.	(Pyralidae)
C. simplex Butl.	,,
C. spp. (2: larvae only)	,,
Leucania acontistis Meyr.	(Noctuidae)
L. phaula Meyr.	,,
L. semivittata Walk.	,,

Oxycanus spp. (2: larvae only)	(Hepialidae)
Orophora unicolor Butl.	(Psychidae)
Persectania atristriga Walk.	(Noctuidae)
P. disjungens Walk.	,,
P. ewingi Westwd.	,,
Brachaspis collinus Hutt.	(Acridiinae)
Locusta migratoria Reich.	(Oedipodinae)
Phaulacridium marginale Walk.	(Acridinae)
Mealybug (1 sp.)	(Margarodinae)
Dictyotus caenosus Westwd.	(Hemiptera)
Hudsona anceps White	,,
Nysius huttoni White	,,
Thrips (2 spp.)	(Thysanoptera)
Costelytra zealandica (White)	(Melolonthinae)
Odontria sp.	,,
Hyperodes griseus Hust.	(Curculionidae)

II. Root feeders:

Chlorochiton convexa Given	(Melolonthinae)
Costelytra zealandica (White)	,,
Odontria spp. (5: larvae & adults)	,,
O. striata White	,,
Pyronota inconstans Brookes	,,
Weevil sp. (larvae only)	(Curculionidae)
Elaterids (3 spp. larvae only)	(Elateridae)
Tipulids, (3 spp. larvae only)	(Tipulidae)
Oxycanus spp. (2: larvae only)	(Hepialidae)
Mealybug (1 sp.)	(Hemiptera)

EXTENT OF DAMAGE BY THE DIFFERENT ORDERS

Lepidoptera. This order occurred in greatest numbers in tussock, and also caused most damage to leaves over the ten-year period of observations. Of the 14 species involved, most damage was done by members of the genera *Crambus, Persectania,* and *Leucania,* but of these it was not possible to state that any one species was causing more damage than the others. Popular belief among tussock-zone farmers is that larvae of this order play a major part in tussock deterioration, but the present observations did not confirm this. There is, however, evidence in the form of frass deposits to indicate that high populations of the noctuids sometimes occur, and it is quite possible that under those circumstances severe damage could result.

Coleoptera. Though eight species of melolonthid adults were collected within tussock by the writer or members of the Ashburton staff, only two were actually proved to be eating leaves, and then only new growth resulting from a burn; their overall influence as leaf-feeders was negligible. On the other hand melolonthid larvae feeding on roots caused sufficient damage in some localized areas to permit grazing stock to pull up whole tussock plants. Elaterid larvae were not numerous, but those of weevils sometimes occurred in relatively large numbers; their influence would be difficult to separate from that of melolonthids. Larvae of *Chlorochiton convexa* Given caused serious damage and tussock loss in small patches up to ¾ acre in extent over fairly extensive areas of the Mt. Highfield Station at Waiau. This is the same insect reported by Lowe (1954) as causing death of the noxious weed nassella tussock.

Costelytra zealandica larvae were responsible for most damage to root systems and they occurred in fairly high numbers even at altitudes of over 4,500 ft. above sea level.

Orthoptera. All three members of this order occurred wherever there was tussock, and, though they fed on leaves, very little impression was made on tussock growth.

Hemiptera. As these insects are sap-feeders, it is difficult to assess their damage, but no definite evidence was collected to show that they were of primary importance. A root-feeding mealybug was sometimes present in large numbers (over 150 per tussock plant), and a large mealybug within the rolled leaves sometimes resulted in a silvery appearance of leaves where high populations were present. *Nysius huttoni* was not uncommon on developing seed heads where feeding was observed to occur.

Thysanoptera. The two species of thrips came into the same category as the Hemiptera so far as assessing damage was concerned; they too, caused a silvering of leaves harbouring large populations, and they also fed on developing tussock seed.

Diptera. In areas of high soil moisture or organic matter, three species of tipulid larvae were sometimes relatively common, and one of them could be found almost anywhere that sampling was carried out. Though it may not be their main item of food, all three species were seen to feed on roots of tussock. The commonest species belonged to the genus *Macromastix*.

General Discussion on Overall Damage

It can be seen from the above that no extensive conspicuous damage could be attributed to any particular insect. Their combined influence, however, is another matter, and it is hardly necessary to point out that 45 different species of insects, often all occurring in the same area, must reduce the vigour of the tussock to some extent at certain stages of growth. Over the period of observation there was no indication that any of the insects was more plentiful than past records or opinions of high-country farmers showed.

Of the insects that caused most damage, not one was free from parasites, predators, or diseases either above or below the ground surface, and it is considered that this factor was responsible for maintaining insect populations at a level where influence on tussock was not of major concern. In relatively small localized areas there were occasional seasons of severe damage till the parasite–host relationship reached what is apparently the normal balance. Another factor that reduces chances of damage to tussock is that melolonthid larvae are cannibalistic; this in the case of plants with poor root systems would assist in keeping populations per tussock at a more or less constant maximum of 6–8 larvae.

Taking a broad view of the tussock insect situation, and ignoring the sporadic occurrence of localized damage, it is considered that the leaf-eating insects observed were beneficial rather than harmful over the period of observation. Individual tussock plants tended to die out in the centre; this had the effect of "pushing" the growing portion outwards in a ring, leaving dead and decaying leafage in the centre. Most

insect damage to leaves occurred to centres of plants, and the accumulation here of frass and its attendant moulds speeded up the decaying process. Whether or not the tendency to die out in the centre is a natural feature of tussock development, the final effect was to produce a central decaying portion of leaf mould which formed an excellent seed-bed for germination of seed from the parent plant—a seed-bed moreover, that was not unduly affected by wind or frost action. Tussock seed was seen to be germinating in this central frass and decay zone in tussock.

When it comes to consideration of the root-eating insects (particularly the melolonthid larvae) there is no doubt that they reduced vigour of tussock over the period of study. Populations as high as 47 larvae under a single tussock were recorded in the present survey, and counts of 3 to 8 per plant were not uncommon averages. The main effect of these insects' activities is to reduce length and number of roots so that tussock cannot utilize plant nutrients at a depth greater than 2–4 in. instead of the 18 in. to over 3 ft. common for the above three species of tussock. The shortened effective root system would not be important in a season of adequate rainfall, but such plants were occasionally adversely affected under local dry conditions at which times they showed noticeably poorer leaf growth than did plants with undamaged root systems.

The movement of ground-inhabiting insects—both plant-feeders and insect parasites and predators—through the soil tended to make the top 3 in. open and crumbly. This permitted frost action to lift root-damaged tussock plants in those relatively small areas where high populations of melolonthids built up to damaging levels. It was responsible also for accelerated wind erosion round margins of tussocks, and, of course, in inter-tussock areas where root-feeding insects caused more damage than under tussock themselves.

Tussock cannot apparently recover quickly from excessive injury, and it is important to recognize this fact when assessing impact of insect or any other type of damage. For exampe, at Waiau where *Chlorochiton convexa* larvae were destroying native tussock in more or less isolated patches, these tussock-free areas are likely to be apparent for over ten years even if this grass grub is eliminated from the area. The reason for this, it is considered, is that whereas native tussock (merely from the fact of its continued existence) must have been able successfully to withstand feeding by this native insect, it does not have the ability also to withstand effects of grazing stock, and feeding and scratching by rabbits. A true assessment of the relative effects of all types of physical injury to tussock could be achieved only after many years of careful checking, but the writer is convinced, as a result of the past ten years' casual observations, that insects could be responsible for some of the clear-cut lines on one side of which there is tussock and on the other no tussock at all, even though there may not be any insects present at subsequent inspections. It is thought, however, that insect larvae "put the finishing touches" to tussock injured by the complex of human, grazing, and other physical disturbances caused by animals.

It is stressed that over the 10-year period of the present studies, there has been no heavy infestation by any of the insects recorded here, so it would not be correct to state that insects are never of major importance

over large areas. All that can be said, is that there are many insects that fed on tussock, a few did periodic, severe, local damage over the period of observation, and that the overall damage was not severe over that period. A small series of insecticide-treated and untreated plots in the Mackenzie Country, however, showed that there is a definite difference between the treated and untreated; this indicates that the overall effect of insects cannot be ignored in making a true survey of tussock deterioration.

Appendix

Previous Records of Insects Eating Tussock

I. Recorded by Hudson (1928, 1934, 1939, 1950):
Aletia griseipennis Feld. on native grasses.
A. temenaula Meyr. on *Poa caespitosa*.
Argyrophenga antipodum Dbld. on *P. caespitosa*.
Crambus simplex Butl. on *P. caespitosa*.
Leucania phaula Meyr. on *P. caespitosa*.
L. semivittata Walk. on native grasses.
Metacrias erichrysa Meyr. on tussock.
Orocrambus mylites Meyr. probably on *P. colensoi*.
Orophora unicolor Butl. probably on tussock.

II. Recorded by Dick (1940):
Leucania acontistis Meyr.
L. toroneura Meyr.
Persectania ewingi Westwd.
Odontria sp. larvae eating roots of *P. caespitosa* and *Festuca novae-zelandiae*.

III. Recorded by Healy (1945):
Odontria spp.
Persectania ewingi Westwd.

IV. Recorded by Given (1952):
Chlorochiton discoidea Broun
C. intermediata Given
C. pulcher Broun
C. simmondsi Broun
Costelytra zealandica (White)
Odontria macrothoracica Given
O. occiputale Broun
O. variegata Given
Mycernus elegans Broun
M. intermediatus Given
Prodontria bicolorata Given
P. capito Broun
P. lewisii Broun
P. modesta Broun
P. pinguis Given
Psilodontria viridescens Broun
Pyronota inconstans Brookes
P. rubra Given
Scythrodes squalidus Broun

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VIRUS SPRAYS FOR CONTROL OF *Pieris rapae* L.

By J. M. KELSEY, Entomology Division, Department of Scientific and Industrial Research, Ashburton.

(*Received for publication, 27 November 1956*)

Summary

A preliminary trial, using a simple technique, showed that it is possible to spread artificially a caterpillar virus in aqueous sprays for control of the common white butterfly. (*Pieris rapae* L.) Possible natural spread of the virus to caterpillars by ovipositors of parasites is discussed.

INTRODUCTION

During the summer of 1947–48 a virus disease of white butterfly larvae exercised an unusually high degree of control, and advantage was taken of this to determine whether the virus could be artificially spread as a controlling agent. This paper gives results of a small-scale trial and though repeat tests gave negative data, it would appear that artificial distribution of this virus is quite possible.

This is not the first record of virus being artificially spread to control caterpillars, as Steinhaus and Thompson (1949, 1950) reported the successful use of a virus to control the lucerne caterpillar *Colias philodice eurytheme* Bdvl. using both ground- and air-applied sprays, and Clark and Thompson (1954) reported results against *Malacosoma fragilis* Stretch.

TECHNIQUE

The source of the virus was a few self-sown rape plants on a vacant Ashburton section; these plants carried a high population of white-butterfly caterpillars, many of which were affected by the disease. The experimental area was an Ashburton home garden where apparently healthy caterpillars were collected off nasturtium and *Cleome spinosa* Jacq; none of these colonies showed signs of the disease.

Nine dilutions of the virus spray were used, and in each case recently dead caterpillars showing the fluid stage of the disease were selected and ground up in a mortar with 2 fluid ounces of tap water. The macerated material was then strained through a single thickness of wet organdie muslin to remove solid matter, and the liquid was then diluted with tap water. The first series used two infected caterpillars; the second, 5; and the third, 10 infected larvae, and three dilutions were made for each series using 1 pint, 4 pints, and 8 pints of tap water.

Sprays were applied within half an hour of preparation, using a hand atomizer, with sheets of newspaper to protect adjacent rows of cabbages during spraying, the newspaper being changed for each concentration of spray. The untreated control row was sprayed first with tap water only.

Plants were inspected to ensure that no white butterfly caterpillars were present and they were then artificially infested with apparently healthy, half-grown larvae at a rate of 6 per plant. There were ten rows, each containing six cabbages so infested. To make sure that all caterpillars had successfully established on their new food plants daily

inspections were carried out over a period of three days before sprays were applied. Nine of the rows were sprayed, and an end row of 6 plants left as control.

Spray concentrations were randomized in rows, but control plants were deliberately kept at the end of the plot to avoid contamination as much as possible. Sprays were applied on a windless day in bright sunlight, and no spray was permitted to run off plants to the ground. Only the top leaf surface was treated, and spray dried within $\frac{1}{4}$ hour. Caterpillars that were not on the upper surfaces thus received no direct spray.

From two days after spraying, at which time all larvae were apparently healthy, the writer was absent for ten days, so day-by-day examination was not possible.

RESULTS

Twelve days after spraying, nearly all larvae on virus-treated leaves were dead and showing typical diseased condition, whereas only one larva on the untreated control plants was dead from the disease. Actual figures are given in the table below:

CONDITION OF LARVAE AFTER 12 DAYS

No. Infected Larvae Macerated	Amount of Water Added to Fluid Macerate		
	1 pint	4 pints	8 pints
2	35 infected 1 alive	36 infected	33 infected 3 alive*
5	36 infected	36 infected	34 infected 2 alive*
10	36 infected	36 infected	34 infected 2 alive*
Control	1 infected 35 alive**		

* indicates that these larvae were missing; it was assumed that they had pupated without becoming virus-infected.

** 5 larvae missing; it was assumed that they had pupated without becoming infected.

In repeat experiments using almost the same technique, but in which the writer was called away for $6\frac{1}{2}$ hours immediately after preparing the sprays, none of the canterpillars developed virus disease. In this second test, cabbages were sprayed before larvae were placed there; this point may be important in liability of larvae to infection.

DISCUSSION

The original experiment indicates that an aqueous virus spray prepared as described could be of possible value as a controlling agent for white-butterfly larvae. Reasons for failure of the second experiment are not known, nor is the exact identity of the virus, but this is being checked overseas. Thompson (1951) reported the appearance in

California of a granulosis virus in larvae of *Pieris rapae*, and there are two virus diseases recorded by Tanada from *P. rapae* caterpillars; a granulosis type (*Bergoldia virulenta* Tanada) recorded in 1953 and a polyhedrosis (polyhedral) type (*Borrelina campeoles* Steinhaus) recorded in 1954.

It is hardly necessary to point out that, if a satisfactory method of artifically spreading the virus disease could be worked out and applied early in an infestation, this type of control would be far superior to that by chemicals. The main advantages would be that they—unlike insecticides—would neither present health hazards nor adversely affect natural enemies of the white butterfly, unless, of course, parasites laid eggs in virus-infected caterpillars, in which case the parasite larvae would be destroyed also.

Parasite Transmission of Virus

A small-scale test was carried out to see whether or not the ovipositor of a parasite could transmit the virus, as this could, conceivably, be a method of carriage in the field. Ten white-butterfly larvae were pricked with an ordinary needle immediately after it had been thrust into a virus-infected caterpillar. Only one of the ten developed the disease, and none of those pricked with a sterile solid needle developed virus. Use of an infected hypodermic needle resulted in all 10 larvae developing the disease, and 2 of the 10 pricked with a sterile hypodermic needle died by shrivelling up—not from the disease.

How closely this test would simulate transmission of the virus by white-butterfly parasites is open to question as it is possible that parasites would not oviposit in infected caterpillars because the latter sometimes show symptoms of the disease within 5 days of infection, and before the pupal parasite, at least, normally attacks them. This parasite has been observed on fully fed larvae showing symptoms of virus, but no eggs were laid, though oviposition occasionally occurred in healthy larvae in the pre-pupal state. The experiment does indicate, however, that a piercing instrument with a hollow cavity is more likely to transmit the disease than is a solid one.

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A BLACK ROT OF THE HOP PLANT

By T. Christie, Cawthron Institute, Nelson

(*Received for publication, 3 December 1956*)

Summary

Inoculation tests have shown that the fungus *Gibberella pulicaris* (Fr.) Sacc. v. *minor* Wr. is capable of causing a black rot of tissue of the hop plant.

Introduction

Phytophthora cactorum (Leb. and Cohn) Schroet. is responsible for the death of many hop plants in the Nelson district. Isolations from dead hop plants consistently yield in addition to *P. cactorum* a species of *Fusarium*. More commonly this fungus is present with *P. cactorum* but it has been isolated from dead hop plants in the apparent absence of the other fungus. Perithecia of a species of *Gibberella* are often found above ground on the bases of bines of hop plants that have died during one growing season and have not been removed until the following season. Wollenweber and Reinking (1935) have described this species of *Gibberella* as *Gibberalla pulicaris* (Fr.) Sacc. v. *minor* Wr., the conidial form of which is *Fusarium sambucinum* Fuck. f.l. Wr.

This association of the fusarium form of *G. pulicaris* v. *minor* with dead hop plants has raised the question whether this fungus is a secondary invader of hop tissue already attacked by *P. cactorum* or whether the fungus in itself is capable of causing a rot of hop tissue.

Inoculation tests to determine this point are described below.

Inoculation of Hop Cuttings

Perithecia of *Giberella pulicaris* v. *minor* were collected from the bases of bines of dead hop plants in an Upper Moutere hop garden. Isolations of ascopores were made from asci in these perithecia and a culture of *Fusarium* from an ascospore was established on potato-dextrose agar.

In May 1954, hop crown cuttings were taken from healthy hop plants of the Californian variety in a Belgrove garden. Ten cuttings were inoculated with the above culture of *Fusarium;* the fungus on agar was appled to freshly cut tissue at the bases of the cuttings and to steam-sterilized soil in 8-in. pots in which the cuttings were placed.

Five cuttings were placed in similar pots with steam-sterilized soil as check plants. Agar only was applied to the bases of these cuttings and to the soil.

All pots were placed outdoors. Four months later all cuttings were examined. Table 1 shows the condition of the plants when they were lifted.

Figure 1 illustrates the nature and extent of dead tissue of two cuttings. Both the cortex and the xylem of dead tissue are stained black. This blackening closely simulates that caused by *P. cactorum*.

Isolations from the dead cuttings and from those with dead tissue only at the bases of the cuttings yielded the same species of *Fusarium*

TABLE 1. CONDITION OF INOCULATED HOP CUTTINGS

	Number of Cuttings	Dead Cuttings	Cuttings with Dead Basal Tissue	Clean Cuttings
Inoculated cuttings	10	5	5	—
Check	5	—	—	5

—*photo: R. Blick.*

Fig. 1.—Dead cutting (left); cutting with dead basal tissue (centre); healthy check cutting (right).

as was inoculated to the plants. No isolations of the fungus were obtained from the check plants.

Two of the five cuttings with dead basal tissue were re-potted in steam-sterilized soil and examined again two months later. One was found to be dead with black tissue throughout the length of the cutting. No further movement of infection was found in the second plant, which was beginning to make good growth from the upper part of the cutting. Isolations of *Fusarium* were made from both these plants.

CONCLUSIONS

From these tests it appears that this species of *Gibberella* is capable of causing a black rot of tissue of the hop plant and bringing about the death of dormant cuttings in the absence of *P. cactorum*.

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EFFECTS OF LARGE ORAL DOSES OF PENICILLIN ON PASTURE-FED LAMBS

By E. D. Andrews*, L. S. Gall†, and L. I. Hart*

(*Received for publication, 6 September 1956*)

Summary

Pasture-fed lambs averaging 40 lb. body-weight were each given three doses of 150,000 units of crystalline sodium penicillin G orally, at intervals of three days and two days between the first and second, and second and third doses respectively.

Seven days after the first dose, penicillin-treated lambs had on an average lost weight, whereas during the same period control animals showed a mean weight increase. Examination of rumen samples showed no definite evidence that penicillin had affected rumen vitamin B_{12} activity. On the other hand rumen function was adversely affected three days after administration of the first dose and after subsequent doses.

After withdrawal of the antibiotic, an apparently complete recovery, as judged by mean weight increase and rumen-function tests, occurred within fourteen days.

Introduction

Little information is so far available concerning the effect of orally administered penicillin upon the health of lambs. Kinsman and Riddell (1952) fed penicillin at the rate of 16 mg. per pound of concentrates to suckling lambs without influencing the rate of weight gains. Tribe *et al.* (1954), working with cobalt-deficient lambs, noted an apparent weight and appetite response to oral supplements of crystalline sodium penicillin G given at the rate of 50,000 units (presumably about 30 mg.) to each lamb each day. Colby *et al.* (1950) found that 100 mg. of penicillin given orally each day caused lambs on a basal ration to go off feed and lose weight. The object of a trial described herein was to determine whether doses of penicillin, each slightly less than that given by Colby *et al.*, and administered only three times in a week instead of daily, would affect pasture-fed lambs with particular reference to rumen vitamin B_{12} activity and rumen function.

Experimental

Six Romney lambs approximately five months old and maintained on ryegrass-white clover pastures were divided into the following two groups, each averaging 40 lb. body-weight.

Group A: Control (2 lambs)

Group B: Penicillin (4 lambs)

On 7, 10, and 12 January 1955, Group B lambs each received orally 150,000 units (approximately 90 mg.) of crystalline sodium penicillin G in 25 ml. of distilled water. At the same time control lambs were dosed 25 ml. of distilled water only. All lambs were weighed at the start of the trial (7 January), again on 14 January, and finally on

* Animal Research Station, Department of Agriculture, Wallaceville.

† Fulbright Fellow to New Zealand, 1954–55. Present address: 127 Biltmore Avenue, Oakdale, Long Island, New York, U.S.A.

26 January. Just before dosing, samples of rumen contents were taken by stomach tube on 10 and 12 January, and again on 14, 18, and 26 January, that is three days and two days after the first and second doses respectively, and two days, six days, and fourteen days after the third and final dose.

For vitamin B_{12} assays and rumen-function tests other than the Gram stain, the coarser plant fragments were removed from each sample by straining through cheesecloth. Gram stains were prepared from a 1/10 dilution of the original semi-solid material. For each group, vitamin B_{12} assays using the cyanide extraction method of Ford (1953) and *Lactobacillus leichmannii* as assay organism (Krieger, 1954) were carried out on rumen liquor from pooled samples taken on 12 and 26 January. Measurements of pH and Eh (in millivolts) were made with a Beckman Model G pH meter using glass and platinum electrodes respectively. Ability of the organisms to digest fibre in the miniature artificial rumen was determined using pure cellulose as substrate. Otherwise the method was as described by Huhtanen *et al.* (1954). Types of organisms shown by the Gram stain and isolated predominant rumen organisms (RO) were examined by methods previously described (Gall and Huhtanen, 1951; Huhtanen *et al.*, 1952; Huhtanen and Gall, 1953a, b). For the purpose of the present paper a "typical" Gram stain is defined as one shown by the rumen flora from normal sheep grazing good ryegrass-white clover pastures. It should consist entirely or mainly of true rumen organisms and show the following characteristics: heavy population of small, medium, and large, straight or curved rods, together with small or medium cocci; large forms should include protozoa, sarcina, asteroides and spirillum; there should be good parasitization of plant fibres. An "atypical" Gram stain is defined as one in which true rumen organisms have partly or completely disappeared. These will, to a greater or lesser extent, have been replaced by abnormal or less desirable organisms, for example, *Streptococcus bovis*, large cocci, cocci in straight or curly chains, and in some cases by clostridial-like rods; parasitization of plant fibres is poor or absent.

Results

All lambs appeared to graze normally until the afternoon of 10 January, following the second dose, when penicillin-treated sheep appeared more restless and showed a greater tendency to visit the water trough. By the afternoon of 12 January, following the third dose, two Group B animals had assumed a dejected appearance and penicillin-treated lambs generally continued to show a greater partiality for water. On the morning of 13 January all lambs appeared to be grazing normally, but during the afternoon the two more dejected-appearing Group B animals appeared rather restless although continuing to graze. During an hour of continuous observation on this afternoon these two lambs were the only ones to visit the water trough. In the remaining thirteen days of the trial no abnormalities in grazing behaviour of penicillin-treated lambs were detected.

During the period within which doses were administered, the weight of one lamb in Group A showed no change and the other lamb gained weight. Over the same period one lamb in the penicillin group (B) showed no change in weight, but the remaining three animals lost weight. In the period following withdrawal of the doses, except

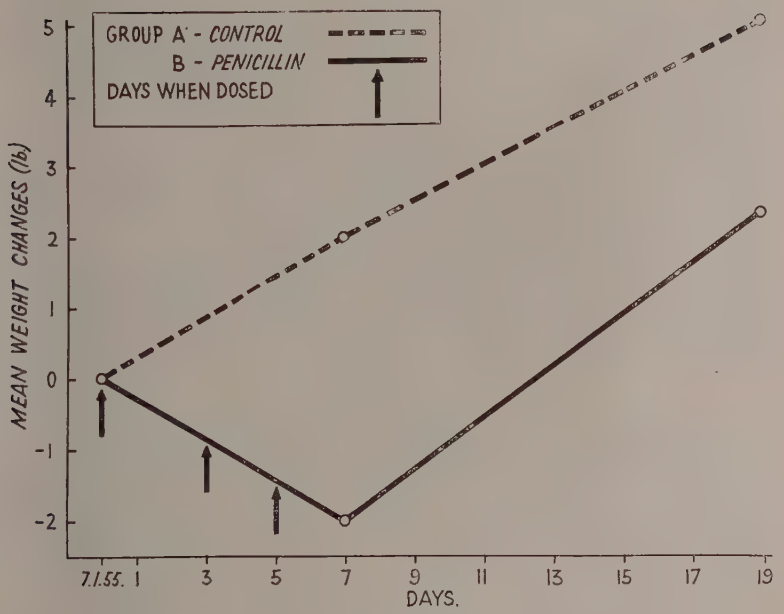

Fig. 1.—Effect of penicillin on lamb weights.

TABLE 1. EFFECTS OF PENICILLIN ON RUMEN FUNCTION
(Dosed on 7, 10, and 12 January 1955)

Sampling Dates January	Group*	Vit. B_{12} activity $\mu g/g$ dry wt. †	pH	Eh	Fibre Digestion (%)	Predominating Rumen Flora		Evaluation
						Gram Stain‡	Cultured Rumen Organisms	
10	A		7.0	—325	56	T	HD, TRC, small H	Good
	B		7.1	—270	18	A	SB, L_2, L_3	Poor
12	A	1.59	6.9	—300	66	T	HD, H	Good
	B	1.56	7.3	—125	25	A	SB, L_2, L_3	Poor
14	A		6.9	—300	64	T	H, HD	Good
	B		7.0	—250	22	A	Small H, HD, SB, PR	Fair
18	A		6.8	—300	51	T	HD, H	Good
	B		6.6	—280	43	A	HD, small H, H, PR, LCC	Fairly Good
26	A	1.04	7.0	—240	48	T	HD, H	Good
	B	0.80	6.9	—215	49	T	HD, H, PR, small H	Good

* A Control : B Penicillin

† Assay organism *L. leichmannii*

‡ T Typical : A Atypical

for one lamb in Group B which showed no weight change, all lambs gained weight. Comparison of mean weight changes for both groups (shown in Fig. 1) suggests that penicillin caused weight losses, but growth was resumed within two weeks after its withdrawal.

Results of determinations of vitamin B_{12} activity and rumen-function tests on samples from each group at the dates shown are given in Table 1. The pH, Eh and fibre digestion figures are group averages. Rumen organisms listed in the table but not referred to in previous publications are RO-SB and RO-small H. RO-SB is the organism referred to elsewhere as RO-6TBR (Gall and Huhtanen, 1951) and is now thought to be identical with *Streptococcus bovis*, while RO-small H is similar to RO-H but has a slightly different morphology (Gall, unpublished). Results from rumen flora studies were evaluated and are discussed in terms of the criteria previously established by Gall and co-workers.

Discussion

Comparison of results from samples taken on 12 January show no evidence that preceding doses of penicillin affected vitamin B_{12} activity. Because weight-change measurements and rumen-function tests (discussed later) indicated that by 26 January penicillin-dosed lambs had recovered from the effects of the antibiotic, the lower vitamin B_{12} activity of the sample from these animals on this date is probably of no significance.

Penicillin administration appeared to have little if any effect on pH values, although the largest difference shown, (on 12 January) of 6.9 for control lambs as against 7.3 for samples from those dosed penicillin, may have been due to treatment. Neglecting the sign, Eh values for the penicillin group were lower throughout the trial as compared with corresponding results for the controls. While the significance of this is not easy to assess, a comparison of trends for penicillin-dosed and control lambs shows that on 12 January there was a sharp fall in figures for the former group only. This indicates that at that time penicillin treatment resulted in decreased anaerobiosis. More striking was the effect of penicillin on the ability of micro-organisms to digest fibre. For samples taken on 10, 12, and 14 January, fibre-digestion figures for the penicillin group were considerably lower than corresponding results for control animals. On 18 January, that is six days after the final doses, fibre digestion for Group B samples had increased markedly, and by 26 January was comparable with that for control lambs. Gram stains from penicillin-dosed lambs were atypical for the first four samplings but at the final sampling were typical. The rumen organisms identified on culture supplement the information obtained from fibre-digestion determinations. In the control sheep the normally found fibre-digesting organisms (RO-HD, RO-TRC, RO-H and RO-small H) predominated throughout the trial, whereas, for the first and second samplings, in the penicillin-treated animals the less desirable, simple carbohydrate-digesting bacteria RO-SB, RO-L_2 and RO-L_3 were predominant. At the third, fourth, and fifth samplings, the rumen populations from Group B lambs showed a progressive return to normal. Integration of the rumen-flora studies at each sampling is shown under "Evaluation" in Table 1. Over all, rumen-function tests show that whereas control animals maintained a fairly constant and normal rumen environment and flora those dosed penicillin showed marked and undesirable changes in this respect.

The rumen picture altered progressively toward normal between the second and fourteenth day after cessation of penicillin treatment.

It is concluded that under the conditions of the experiment, 150,000 units of crystalline sodium penicillin G orally administered to 40-lb. pasture-fed lambs adversely affects growth and rumen function, but after withdrawal of the antibiotic an apparently complete recovery occurs within fourteen days.

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EFFECTS OF ORALLY-ADMINISTERED PENICILLIN ON COBALT-DEFICIENT AND COBALT-DOSED LAMBS

By E. D. Andrews*, L. S. Gall†, L. I. Hart*, and J. P. Anderson‡

(*Received for publication, 6 September 1956*)

Summary

Cobalt-deficient lambs showed an apparent response to 50,000 units of crystalline sodium penicillin G given orally thrice weekly for nine weeks and thereafter daily for ten weeks, but the response was slight as compared with that obtained from oral doses of cobalt sulphate at the rate of 7 mg. cobalt a lamb a week.

Lambs given cobalt plus penicillin showed a significantly greater growth response than those given cobalt alone.

Penicillin did not appear to increase the synthesis of vitamin B_{12} in the rumens of either cobalt-deficient or cobalt-dosed lambs.

The rumen flora of cobalt-deficient animals was altered from normal. The presence of long segmented rods was peculiar to cobalt-deficient lambs not receiving penicillin.

In both cobalt-deficient and cobalt-dosed lambs penicillin modified rumen function. In particular the ability of rumen organisms to digest fibre was reduced.

Although, under present experimental conditions, 50,000 units of penicillin, given daily, increased growth rates, results showed that in general the amount of single oral doses liable to affect adversely the health and growth of lambs may not greatly exceed this figure, and is probably appreciably less than 150,000 units.

Introduction

Stokstad (1954) has reviewed the possible effect of orally administered antibiotics in reducing vitamin B_{12} requirements of animals. While most of the data indicate that antibiotics are not capable of eliminating the need for vitamin B_{12}, some investigators have reported that under certain conditions antibiotics can produce in man, rats, pigs, and chicks responses similar to those of vitamin B_{12}.

Since a number of workers have shown that cobalt-deficiency disease in ruminants is due to a deficiency of vitamin B_{12}, it would seem possible that cobalt-deficient animals might respond to antibiotics. Tribe *et al.* (1954) have in fact reported such a response. These workers found that cobalt-deficient sheep fed a low-cobalt ration of hay and concentrates showed greatly improved body-weight gains and increased food intake following oral administration of crystalline sodium penicillin G at a rate of 50,000 units a sheep a day. However, only two sheep were used, and the experiment was uncontrolled in that no untreated cobalt-deficient animals were available for comparison.

The object of experiments described in the present paper was to determine the effects of penicillin on cobalt-deficient and cobalt-dosed lambs grazing cobalt-deficient pasture, as measured by growth rates, rumen vitamin B_{12} activities, and rumen-function tests.

* Animal Research Station, Department of Agriculture, Wallaceville.

† Fulbright Fellow to New Zealand, 1954–55. Present address: 127 Biltmore Avenue, Oakdale, Long Island, New York, U.S.A.

‡ Department of Agriculture, Invercargill.

EXPERIMENTAL

Animals used were Southdown-Romney cross-bred lambs which so far as could be ascertained had all been born within the month of September 1954. They had been confined since birth to a paddock which had produced cobalt-deficiency disease in lambs in previous years. Pastures consisted essentially of perennial ryegrass, white clover, and dogstail. At intervals before and during the experimental period pasture samples were taken for cobalt analyses.

Trial I

On 16 December 1954, 28 lambs were assigned at random to the following three groups:

Group A	....	Control (10 lambs)
Group B	....	Penicillin (10 lambs)
Group C	....	Cobalt (8 lambs)

All lambs were weighed at weekly intervals.

Owing to difficulty in arranging for dosing to be carried out daily during the early part of the trial, consideration was at first given to the possibility of administering penicillin to Group B sheep in amounts equivalent to 50,000 units a lamb a day, but given as larger doses thrice weekly. Meanwhile, however, other work (Andrews *et al.*, 1957) indicated that single large doses of that order might adversely affect growth and rumen function. Consequently single doses were kept to what appeared to be the safe level of 50,000 units (approximately 30 mg.) of crystalline sodium penicillin G (Tribe *et al.*, 1954) and for the first nine weeks of the trial were given as one fluid ounce of aqueous solution to each sheep thrice weekly. After the ninth week more assistance was available and the rate was increased so that 50,000 units were given to each sheep daily for the next ten weeks. Cobalt sulphate solution was administered orally to Group C sheep at the rate of 7 mg. cobalt a lamb a week (Lee, 1950) throughout the trial which was continued until 27 April 1955, a period of nineteen weeks.

Trial II

During February 1955 a further mob of eighteen lambs that had been confined since birth to the same paddock as the Trial I animals became available for experiment. These were then showing signs of cobalt deficiency as judged by small and erratic weight changes. On 16 February they were divided into two supplementary groups of nine lambs each, and given the following treatments:

Group C^1	Cobalt 7 mg. a lamb a week.
Group D	Cobalt 7 mg. a lamb a week, plus penicillin 50,000 units a lamb a day.

Except for one weighing missed between the fifteenth and seventeenth week, lambs were weighed at weekly intervals. This trial was concluded on 15 June 1955, a period of seventeen weeks.

Vitamin B_{12} Assays and Rumen-function Tests

On 27 March, five animals from each of the four groups, A (control, Trial I), B (penicillin, Trial I), C (cobalt, Trial I) and D (cobalt plus penicillin, Trial II) were sampled by stomach tube for

rumen contents. Vitamin B_{12} assays, and rumen-function tests other than the Gram stain, were carried out on filtrates after straining through cheesecloth. Gram stains were made from a 1/10 dilution of the semi-solid original material.

Microbiological assays for vitamin B_{12} activity were carried out on pooled samples from each of the four groups. Samples were prepared for assay using the cyanide extraction method of Ford (1953a). Two test organisms, *Lactobacillus leichmannii* and the chrysomonad, *Poteriochromonas stipitata,* were used. *L. leichmannii* responds to Factor A and pseudo-vitamin B_{12} (Ford 1953b), and deoxyribosides (see review by Marston, 1952) besides true vitamin B_{12} (cyanocobalamin), while *P. stipitata* is reported to be specific for cyanocobalamin (Barber *et al.,* 1953). Assay procedures were essentially those of Krieger (1954) for *L. leichmannii* and Barber *et al.* (1953) for *P. stipitata.*

Using the techniques of Gall and co-workers indicated elsewhere (Andrews *et al.,* 1957) rumen samples were examined for pH and Eh, ability of the organisms to digest fibre in the miniature artificial rumen (Huhtanen *et al.,* 1954), types of organisms as shown by the Gram strain, and isolated predominant rumen organisms (RO) grown and identified by methods previously described (Gall and Huhtanen, 1951; Huhtanen *et al.,* 1952; Huhtanen and Gall, 1953a, b). Gram stains were classified as "typical" or "atypical" in terms of the definitions given elsewhere (Andrews *et al.,* 1957).

RESULTS

Cobalt Content of Pastures and of Penicillin

Cobalt contents of pasture samples obtained before and during the experimental period are shown in Table 1.

TABLE 1. PASTURE COBALT (p.p.m. on dry wt.)

Month Sampled		Cobalt
1954	September	0.09
	November	0.08
	December	0.07
1955	January	0.08
	February	0.17*
	April	0.10
	May	0.08

* Probably soil-contaminated

If the February figure is neglected the mean cobalt content is about 0.08 p.p.m., an amount liable to be insufficient for lambs (Andrews, unpublished; Marston, 1952).

No cobalt could be detected in a sample of penicillin representative of that used in Trials I and II.

Weight Responses, Trial I

During the trial period there were three deaths in the control group (A). There were no deaths in the other two groups during this time although one lamb from the penicillin group (B) died in the week following the end of the trial. The cobalt content (0.06 p.p.m.) of the liver from this animal was consistent with cobalt-deficiency disease (McNaught, 1949). The cobalt content of a liver from one of the control-group animals that died was also low (0.03 p.p.m.).

Mean weight changes of animals in the three groups are compared in Fig. 1. Weights for control lambs are shown as means for survivors at each weighing. Also shown are means adjusted to include the final weights of three lambs that died between the tenth and sixteenth week. On the latter basis, after the fourth week mean live weights calculated for control lambs progressively declined. The penicillin group (B) gained a mean of 8.1 lb. There is no obvious indication that 50,000 units given daily after the ninth week conferred any greater benefit than the same amount given thrice weekly. Group C lambs showed a clear response to cobalt and gained a mean of 28.5 lb. The mean gain made by the

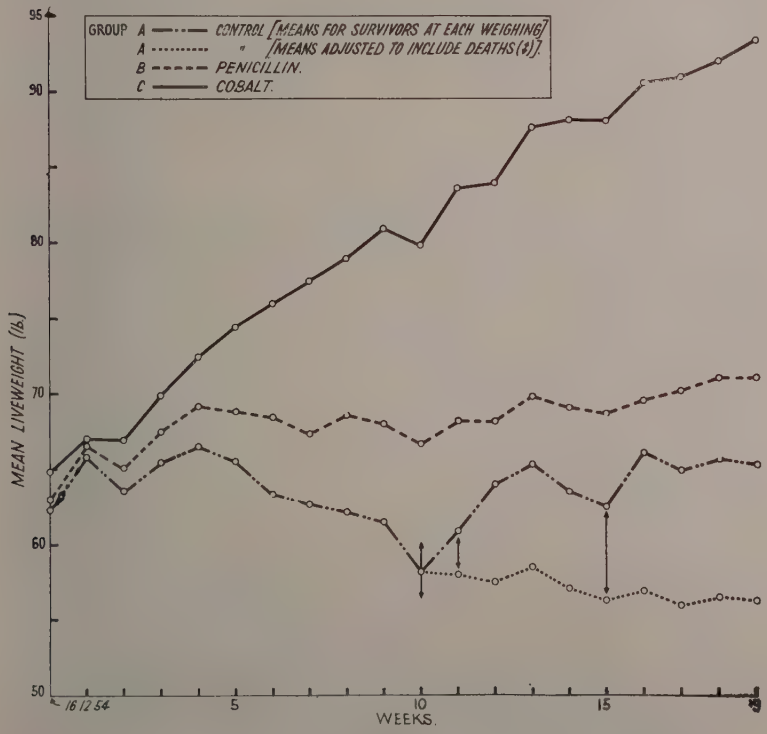

Fig. 1.—Weight responses of cobalt-deficient lambs to cobalt and to penicillin.

cobalt group is highly significantly greater ($P < 0.01$) than that made by lambs in the penicillin group (B), and the mean gain calculated for surviving animals in Group A (control). For Groups B and A the mean weight-change difference in favour of the penicillin group is significant ($P < 0.05$) only if the weights of the animals that died in the control group are taken into account.

Weight Responses, Trial II

During the first week of this trial one poorly conditioned lamb in Group C^1 died. Thereafter no deaths occurred in either group, and apart from a setback from some unknown cause in the first week, all lambs showed a good response to treatments. As indicated in Fig. 2

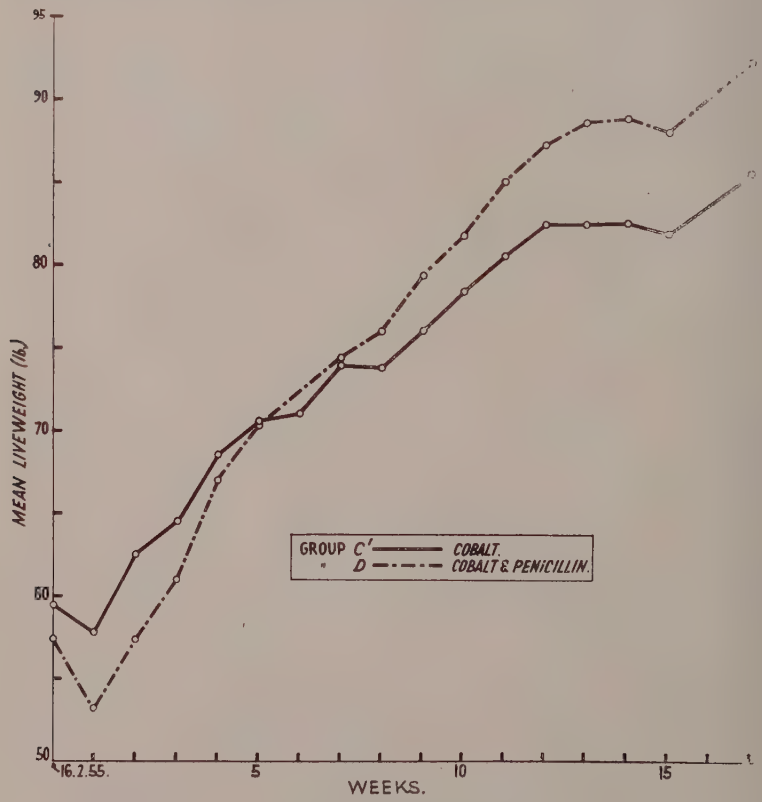

Fig. 2.—Weight gains of cobalt-deficient lambs given cobalt and cobalt plus penicillin.

the cobalt-dosed group (C^1) gained an average of 26.2 lb., whereas Group D lambs given cobalt plus penicillin showed a mean gain of 34.9 lb. The 8.7 lb. difference in favour of the lambs receiving penicillin in addition to cobalt is just significant ($P < 0.05$).

Vitamin B_{12} Assays and Rumen-function Tests

TABLE 2. VITAMIN B_{12} ACTIVITIES OF RUMEN SAMPLES (μg/g. on dry wt.)

Group	Assay Organism		Ratio a/b
	L. leichmannii a	*P. stipitata* b	
A. Control	1.16	0.69	1.7
B. Penicillin	0.72	0.56	1.3
C. Cobalt	1.09	0.68	1.6
D. Cobalt + Penicillin	0.88	0.61	1.4

Table 2 shows that for both test organisms the vitamin B_{12} activities of samples from the control group were comparable with corresponding results from the cobalt group. Ratios of activities measured by *L. leichmannii* to those measured by *P. stipitata* were also similar. Samples from the penicillin and cobalt plus penicillin groups showed somewhat lower vitamin B_{12} activities and activity ratios.

Table 3 shows little difference in pH, the mean for the cobalt group being slightly lower than the means for the other three groups. Means for Eh determinations show that samples from the two groups of animals receiving cobalt were more anaerobic than those receiving no cobalt, the least anaerobic conditions being associated with the penicillin group (B). Mean fibre digestion for the cobalt group (C) was 70% while the control group showed a breakdown of only 59%.

Fig. 3.—Long segmented rods found only in rumen contents of untreated cobalt-deficient (group A) lambs.

TABLE 3. RUMEN FUNCTION TESTS

Group[1]	Lamb No.	pH	Eh	Fibre Digestion (%)	Predominating Rumen Flora		
					Gram Stain[2]	Cultured Rumen Organisms	Evaluation
A	525	6.6	—210	57	A*	HD, thin rods, H, SB.	Fair
	504	7.0	—280	73	A*	HD, SB.	Fair
	539	6.6	—210	57	A*	SB, PR, HD.	Fair
	532	7.1	—340	48	A*	HD, H, SB.	Fair
	502	7.3	—310	—	A*	H, HD, SB.	Fair
	Means	6.9	—270	59			
B	531	6.2	—270	21	A	H, SB, HD.	Fairly good
	528	7.0	—230	47	A	HD, SB.	Fair
	540	7.3	—200	48	A	SB, HD.	Fair
	530	—	—	46	A	H, HD, SB.	Fairly good
	512	7.0	—260	17	T†	SB, small H.	Fair
	Means	6.9	—240	36			
C	510	6.4	—230	83	T	HD, SB.	Fairly good
	533	6.8	—350	83	T	H, HD, SB.	Good
	548	6.7	—310	55	T	H, HD, SB.	Good
	544	6.8	—310	65	T	SB, HD, H.	Good
	524	7.1	—300	63	T	H, HD.	Good
	Means	6.8	—300	70			
D	522	7.3	—310	42	T	HD, SB.	Fairly good
	520	6.9	—260	45	A	H, HD.	Fairly good
	506	6.9	—310	48	A	H, HD.	Fairly good
	526	7.1	—340	57	T	H, HD.	Fairly good
	541	7.3	—320	—	A	H, HD.	Fairly good
	Means	7.1	—308	48			

[1] A Control; B Penicillin; C Cobalt; D Cobalt + Penicillin.

[2] A Atypical; T Typical.

* Long segmented rods.

† Except for a few curved rods.

Both groups of animals fed penicillin (Groups B and D) showed lowered ability to digest fibre with means of 48% for the cobalt plus penicillin group and only 36% for the penicillin group. As judged by Gram stains, control lambs showed an atypical rumen flora with a characteristic long segmented rod in samples from all five of these animals (Fig. 3). This rod was not found in any of the other animals. The cobalt group (C) showed a typical rumen flora. The picture was more irregular in the cobalt plus penicillin and penicillin groups. Three out of five animals given cobalt plus penicillin showed an atypical flora and two were typical. Of the penicillin-fed lambs (Group B) four showed a markedly atypical flora while one animal was slightly atypical. These results

were substantiated to some degree by the cultural findings. The organisms isolated from cobalt-dosed animals (Group C) were quite satisfactory in four cases and only somewhat less satisfactory in one (No. 510). The prevalence of RO-SB in three out of five animals was, however, a somewhat unusual finding. The organisms isolated from control lambs were somewhat less desirable in most instances and were distinctly abnormal in one animal (No. 525). In the penicillin group the pattern was somewhat similar to that found in the control group, but the flora in the cobalt plus penicillin group was distinctly superior in four lambs, only one (No. 522) showing an abnormal picture. Although not given in the table, physiological differences as shown by gas formation and the presence of clumps were also observed. Heavy gas formation was observed in three of the four groups, with only the penicillin-fed animals (Group B) showing lower gas formation. This group showed only one culture that formed clumps, although this characteristic was found sporadically in the other three groups. Anaerobes predominated in all groups except the penicillin group where all five animals showed facultative anaerobes.

DISCUSSION

Results from Trial I (Fig. 1) suggest that to some extent penicillin stimulated the growth rate of cobalt-deficient lambs. The findings do not, however, fully support those of Tribe *et al.* (1954) since the apparent effect of penicillin was only slight as compared with that due to cobalt. Cobalt-dosed lambs also showed a response to penicillin (Trial II, Fig. 2). Findings from Trials I and II are capable of two alternative interpretations:

(a) That penicillin does in fact reduce vitamin B_{12} requirements to some extent. But if this is true, it follows that 7 mg. cobalt given to cobalt-deficient lambs at weekly intervals does not necessarily provide sufficient vitamin B_{12} for continuous optimal growth.

(b) That growth stimulation by penicillin is not mediated through vitamin B_{12}.

No definite evidence in favour of either of these possibilities is provided by the present work. A controlled experiment in which penicillin-fed lambs were given a diet continuously adequate in cobalt might throw light on this question. It is, however, of interest that the vitamin B_{12} activities of rumen samples from the two penicillin-fed groups (B and D, Table 2) were actually lower than corresponding figures for the other two groups. This suggests that penicillin does not encourage the bacterial synthesis of vitamin B_{12} in the rumen as postulated by Tribe *et al.* (1954), but leaves open the question of a possible effect on vitamin B_{12} utilization.

An unexpected finding was that rumen samples from cobalt-dosed sheep contained no more vitamin B_{12} than those from cobalt-deficient control animals. However, samples were secured one week after the previous cobalt dose had been given and recent Australian work (Hine and Dawbarn, 1954) indicates that rumen vitamin B_{12} values, although high soon after cobalt dosing, would be expected to fall sharply to original level within 5–7 days.

The vitamin B_{12} activities of whole rumen ingesta from cobalt-deficient sheep have been measured with *L. leichmannii* by Hoekstra, Pope, and Phillips (1952), and by Hine and Dawbarn (1954). Results found by these two groups of workers are in general agreement. Present results are of the order of ten times more than those found by the other workers. At least part of this difference may be due to the fact that the coarser plant fragments probably contain relatively little vitamin B_{12} activity on a dry-weight basis, and in the present work this fraction was separated from the samples before assay.

In terms of all the rumen-function tests, the writers consider that cobalt-dosed lambs showed the most satisfactory rumen picture followed by control, cobalt plus penicillin, and penicillin-fed animals in that order (Table 3). Tests indicate that, in cobalt deficiency, anaerobiosis is decreased, the ability of rumen organisms to digest fibre is reduced, and, confirming the results of Gall *et al.* (1949), some changes in the rumen flora occur. The presence of long segmented rods (Fig. 3) appears to be confined to cobalt-deficient animals, but these organisms do not appear when penicillin is fed. Penicillin feeding tends to result in an abnormal rumen flora. In particular, a comparison of figures from Groups A and B and those for Groups C and D indicates that at the level given the antibiotic reduces the ability of rumen organisms to digest fibre. It is of considerable interest that penicillin, at the rate administered in the present trials, appears to stimulate the growth of cobalt-deficient lambs and those given 7 mg. of cobalt once weekly, despite physiological changes induced in the rumen.

A comparison of present results with those recorded by Andrews *et al.* (1957) shows that while 50,000 units of penicillin daily (i.e. 350,000 units in a week) fed to lambs initially about 60 lb. body weight was associated with moderate alteration of rumen function but increased growth rate, 150,000 units fed thrice weekly (i.e. 450,000 units in a week) to 40 lb. lambs was accompanied by marked and undesirable changes in rumen function and a decline in mean body weight. It seems reasonable to suppose that the effect of penicillin on rumen function and body weight depends upon the size of the animal and its rumen, the amount of each single dose, and the frequency with which it is administered. However, present findings, together with those of Andrews *et al.* (1957), show that in general the amount of single oral doses of penicillin liable to affect adversely the health and growth of weaned pasture-fed lambs may not greatly exceed 50,000 units and is probably appreciably less than 150,000 units.

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VARIATIONS IN TOMATO FLOWERS AND FRUITS

By T. P. Palmer, Crop Research Division, Department of Scientific and Industrial Research, Christchurch

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Summary

The numbers of sepals, petals, anthers, and locules were counted on fruits of some plants of Ailsa Craig and Harbinger and U.C. 156.

The number of sepals and petals varied from 5 to 8, and fruits had 2 or 3 locules. Each flower usually had the same number of petals and sepals. In the small sample of flowers whose anthers were counted, the number of anthers on Ailsa Craig and Harbinger varied with the number of petals and sepals, but in U.C. 156 this was not the case.

In Ailsa Craig, the first flower on a truss was more likely to have 7 sepals and petals, but in Harbinger no such effect was detected.

Fruits with three locules were more common later in the flowering season, or on later trusses. Their frequency was increased by removing the laterals as these were formed.

Introduction

Cooper (1927) described the tomato flower as typically hexamerous, and mentioned that several workers had recorded this condition. On the other hand he noted that Bailey (1924), Gray (1908), and Payer (1857) described the whole order Solanaceae as pentamerous. Thompson (1923) described the tomato flower as pentamerous, and Britton and Brown (1898) recorded it as pentamerous, rarely hexamerous (all quoted by Cooper).

In 1955 and again in 1956 the numbers of floral parts in the tomato varieties Ailsa Craig and Harbinger were recorded. Some flowers of U.C. 156* were also examined. These results show the reasons for the differing opinions expressed by these authors, and in addition reveal some patterns in the variations in tomato flower parts.

Material and Methods

In 1955, five plants of Ailsa Craig and four of Harbinger were grown in an unheated greenhouse. Two of the Harbinger plants (H2 and H4) had one divided cotyledon. None of the plants were pruned i.e. laterals or leaves were not removed. When each flower opened, the number of petals and the date were recorded. When each fruit ripened, the numbers of sepals and locules and the date were noted.

In 1956, six plants of each variety were grown. Two of the Harbinger plants (H9/1 and H9/2) were cuttings from H9 grown in 1955. The two varieties were sown at different times and planted in different parts of the greenhouse. The laterals were removed as they developed from three plants of each variety.

The same observations were made as in 1955. Some flowers on plants of U.C. 156 growing in another greenhouse were also examined.

* ex University of California, Davis, California.

RESULTS 1955

TABLE 1. TOMATO FLOWERS 1955

Plant	Trusses	Flowers	Distribution of Petal Nos.			First Flowers with 7 petals	Flowers with 7 sepals	First Flowers with 7 sepals	Discordant Flowers
			5	6	7				
AC1	13	79	28	49	2	2	3	2	11
AC2	19	103	31	63	9	5	12*	6	8
AC5	11	60	15	42	3	1	1	0	2
AC6	19	94	36	53	5	4	6	4	7
AC9	13	75	37	34	4	2	5	1	3
	75	411	147	241	23	14	28	13	31
H2	9	52	21	30	1	0	1*	0	8
H9	9	54	27	26	1	0	1	0	1
H4	13	78	28	44	6	2	7	3	8
H7	13	72	10	58	4	1	8	3	6
	44	256	86	158	12	3	17	6	23

AC = Ailsa Craig. H = Harbinger.

* Includes one flower with 8 sepals.

Flowers on plants of both varieties usually had five or six petals and sepals, though some had seven petals. Flowers usually had the same number of petals as sepals, and the proportion with different numbers was small. The number of petals and sepals on some of these "discordant" flowers may have been wrongly recorded, as sometimes partial fusion of petals or of sepals occurred, and may have been overlooked on some occasions. However, some genuine cases of undoubted discordance were recorded.

In Ailsa Craig, flowers with 7 petals and sepals were much more commonly the first flower on a truss than would be the case if they were randomly distributed on the plant. In Harbinger, no such tendency was detected. Twenty-two fruits of Harbinger and sixteen of Ailsa Craig had three locules instead of the usual two.

RESULTS 1956

Variation in numbers of petals and sepals followed the same pattern as in 1955. In Ailsa Craig, about a third of the first flowers on trusses had seven petals or sepals while the over-all frequency of these flowers was about one in fourteen. In Ailsa Craig, three flowers with eight petals and four with eight sepals occurred. Flowers usually had the same number of petals as sepals, but in some flowers the number was not the same. Fruits with three locules were more common in 1956.

The proportion of fruits with three locules was much higher on the later trusses, and on the pruned plants. The number of petals, sepals, and anthers on 26 flowers of Ailsa Craig and Harbinger were

TABLE 2. TOMATO FLOWERS 1956

Plant	Trusses	Flowers	Distribution of Petal Nos. 5	6	7	First Flowers with 7 Petals	Flowers with 7 Sepals	First Flowers with 7 Sepals	Discordant Flowers
AC 160/1†	7	51	14	35	2*	1	2*	1	3
2	5	44	15	23	6	4	7*	4	4
3†	7	66	13	48	5*	2*	5*	2*	3
4	6	42	13	28	1	1	2	2	3
5†	6	52	14	33	5*	3*	4*	3*	3
6	5	31	9	21	1	1	1	1	0
	36	286	78	188	20	12	21	13	16
H9/1†	6	57	19	35	3	0	2	0	6
H9/2	7	40	18	22	0	0	2	0	2
H11	6	56	14	39	3	0	3	0	6
H12†	6	93	23	62	8	1	9	1	10
H13†	6	72	24	45	3	2	3	3	6
H14	5	63	17	42	4	1	5	1	9
	36	381	115	245	21	4	24	5	39

AC = Ailsa Craig. H = Harbinger.
* Each of these totals includes one flower with 8 petals or sepals.
† Pruned.

TABLE 3. NUMBERS OF FRUITS WITH TWO AND THREE LOCULES

Ailsa Craig

	Pruned								Not Pruned							
Plant	160/1		160/3		160/5		Total		160/2		160/4		160/6		Total	
	2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3
Truss 1	8	0	6	1	8	1	22	2	6	0	7	0	4	0	17	0
2	8	0	9	0	6	0	23	0	7	1	11	1	4	0	22	2
3	7	2	8	2	6	1	21	5	8	0	7	0	7	0	22	0
4	8	0	7	2	14	1	29	3	5	0	6	1	10	0	21	1
5	7	3	5	7	5	2	17	12	4	1	4	1	7	0	15	2
6	5	1	14	7	16	4	25	11			3	1			3	1
Total	43	5	49	19	45	9	137	33	30	2	38	4	32	0	100	6

Harbinger

	Pruned								Not Pruned							
Plant	H9/1		H12		H13		Total		H9/2		H11		H14		Total	
	2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3
Truss 1	7	0	10	1	8	2	25	3	8	0	7	0	7	3	22	3
2	8	1	19	0	17	0	44	1	8	0	10	0	14	1	32	1
3	13	2	6	5	10	1	29	8	7	1	8	2	9	2	24	5
4	4	4	9	6	6	3	19	13	4	2	6	2	11	2	21	6
5	6	6	18	9	5	3	29	18	4	0	5	1	8	0	17	1
6	5	1	4	6	12	5	21	12			12	4	6	0	18	4
Total	43	14	66	27	58	14	167	55	31	3	48	9	55	8	134	20

also counted. Thirteen flowers had five petals, sepals, and anthers, eleven had six, and two had seven. Among the 19 flowers of U.C. 156 that were examined, 15 had 6 petals, and four had five. Thirteen had 6 sepals, five had 7, and one had eight, while the number of anthers varied from six to ten.

DISCUSSION

We have seen that the number of tomato flower parts can vary on the same plant. It is known that the number of locules in tomato fruits is partly determined by genotype (Powers 1940), and the variation in other flower parts may also be genetically determined. The "controversy" as to whether typical tomato flowers have organs arranged in whorls of five or six is seen to be pointless.

Flowers usually had the same number of petals and sepals, and, in Ailsa Craig and Harbinger, the number of petals, sepals, and anthers was usually the same. These results suggest that either the number of petals and anthers is generally determined by the number of sepals, which are formed first (Cooper 1927), or that variations in numbers of organs on each flower are determined by some common cause. Had the numbers of parts been invariably the same on each flower, the first assumption would be more likely. The second assumption may better explain the occurrence of "discordant" flowers, and in U.C. 156 these were very common.

That the number of petals and sepals was not determined solely by chance is shown by the higher frequency of flowers with seven parts among the first flowers formed on a truss in Ailsa Craig. Numerous authors have shown that the first flowers formed are often more prone to be abnormal than later ones. In *Diplotaxis,* some flowers have seven anthers, and these also are most frequently the first flower formed on a branch (Palmer, unpublished).

Again, the number of locules in the fruits of these varieties was not determined by chance. Later fruits, or fruits on later trusses, were more likely to have three locules. On pruned plants the frequency of fruits with three locules was higher. From the data available, it is not possible to determine whether this pattern of occurrence is determined by truss *per se,* by the aging of the plant, or by some external factors. Lewis (1953) found that rogue seedlings more commonly arise from fruits of the 3rd and 4th trusses of Ailsa Craig, and Haskell (1954) has shown that the proportion of tricotylous seedlings varies from truss to truss. These authors suggest that these variations are determined by position *per se,* which may not be the case. Haskell has postulated that these differences reflect changes in hormone production or distribution in the plant. It is at least plausible to suggest that the variations reported here also arise from variations in hormone status.

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PHOTOSENSITIVITY DISEASES IN NEW ZEALAND

X. THE GUINEA PIG AS AN EXPERIMENTAL ANIMAL IN THE INVESTIGATION OF FACIAL ECZEMA

By D. D. Perrin, Ruakura Animal Research Station, Department of Agriculture, Hamilton

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Summary

Procedures using guinea pigs have been developed for testing dried pasture samples, and extracts prepared from them, for the factor which produces the liver damage typical of facial eczema. The results show good reproducibility.

Grades of liver damage produced under standard conditions are outlined.

Liver damage continues when guinea pigs are returned to normal diets. The terminal result in guinea pigs with affected livers is described.

Bilirubinaemia and mild photosensitivity have been produced in guinea pigs fed highly toxic dried pasture and extracts, but, with most of the toxic samples available, liver function tests have revealed little abnormality.

Hepatomegaly is regularly found in guinea pigs with severe facial-eczema liver damage.

Rats, mice, and chickens do not appear to be sensitive to the liver-damaging substance.

Introduction

In an earlier paper in this series[1] it was established that liver lesions similar to those typical of facial eczema in sheep could be produced in guinea pigs fed on grass collected and dried during an outbreak of this disease. Guinea pigs of 200–300 g. bodyweight were used and feeding periods of 3–6 weeks produced typical liver damage. This observation has provided a basis for testing grass extracts in the subsequent chemical investigation of the liver-damaging substance involved (E. P. White, pers. comm.), and has facilitated work on the pathology and biochemistry of the disease. However, because of the considerable difficulty and uncertainty in securing and preserving toxic grass, further reduction of the amount of material required per test was desirable. This paper reports experiments with smaller guinea pigs and modifications of technique which have substantially reduced the amount of grass required and outlines the standard procedures now in use for testing dried pasture samples, and extracts made from them, for the facial-eczema liver-damaging substance. The evaluation of the level of toxicity by visual examination of the liver is also described. Liver-function tests applied to guinea pigs and observations on the development of the liver lesions are reported.

Classification of Liver Damage

The primary lesion in facial eczema is a mild to severe inflammation of moderate-sized bile ducts. This inflammation is associated with degeneration and necrosis of bile-duct epithelium and a progressive periductal fibrosis which frequently terminates in complete replacement of sections of the bile duct by dense fibrous tissue. This is followed by a spectacular proliferation of the perilobular bile ductules distal to

the obstructed ducts, the areas of proliferation appearing to the naked eye as light patches in an otherwise normal-coloured liver. In the guinea pig these areas are generally more or less circular, several millimetres in diameter at the surface, and extend as cones into the liver. If sufficient damage occurs, the light patches are so numerous that entire lobes or the whole liver become uniformly light in colour. These areas invaded by bile duct epithelium and fibrous tissue are firmer and the surface is less smooth than normal. When the liver-damaging substance is fed over a period of some weeks, obliterative and proliferative changes proceed simultaneously. No differences due to sex have been observed.

Although no precise measurement of toxicity of extracts or of pasture samples is at present possible, an approximate assessment can be made by observing the degree of liver damage produced under a standard feeding procedure. Based on an examination of over 100 affected guinea pig livers, using feeding periods of four or five weeks, the following grades of liver damage are distinguished:

1. Normal;
2. Abnormal, not definitely facial eczema;
3. Mild facial eczema;
4. Moderate facial eczema;
5. Severe facial eczema;
6. Very severe facial eczema.

The description of grades (3) to (6) is as follows:

3. *Mild Facial Eczema*

The liver weight lies within the normal range and the colour is also normal. However, careful examination of the liver surface reveals numerous small, lightish patches, giving a flecked appearance which should not, however, be confused with the white spots observed in pasteurellosis.

Histologically there is an obliterative cholangitis and some proliferation of bile-ductule epithelium. There may be some foci of necrosis.

4. *Moderate Facial Eczema*

The liver is increased in weight and shows considerable flecking over most of its surface with patches of light-brown tissue making up about one to three-quarters of its surface.

Histologically there is extensive obliterative cholangitis and associated with this a considerable proliferation of the bile-ductule epithelium giving a blotchy appearance under low power. Much apparently normal parenchymal tissue still survives. The necrotic lesions are more pronounced.

5. *Severe Facial Eczema*

The liver is considerably increased in size and weight and is generally light in colour. The surface is conspicuously flecked throughout, it no longer appears smooth, and it frequently shows a fine greenish-grey network, probably due to degraded bile pigment. Occasionally, necrotic areas several millimetres in diameter are seen and these are

frequently stained yellow or green. The liver feels gritty and rubbery when cut and the exposed surfaces have a fibrous appearance.

Histologically, the proliferating bile-duct epithelium is a most striking feature, masses of tubules and undifferentiated epithelium often occupying more than half of the liver section. Fibrous tisssue is also considerably increased. Greenish-yellow granules of bile pigment may be present. In many cases, numerous necrotic foci are found, varying in size from three or four parenchymal cells up to patches some millimetres in diameter. In portal tracts bile ducts have frequently been obliterated and replaced by fibrous tissue and masses of smaller ductules. The surviving parenchymal tissue does not show any gross abnormality.

6. *Very Severe Facial Eczema*

The amount of liver damage is such that the animal does not survive the four-week test period. At death, the animal is jaundiced and the body tissues are bile stained. Damage to the smaller bile ducts is considerable but, if the survival time is short, weight increase of the liver, loss of colour, and amount of proliferation may be small.

To date, of more than 20 toxic dried grass samples fed to guinea pigs, only one has consistently produced lesions of this severity. However, these were also obtained from another sample by preparing extracts and feeding them at a higher concentration.

More detailed accounts of the histopathology of this disease in guinea pigs and sheep have appeared in earlier papers[1, 2].

STANDARD FEEDING PROCEDURES

A severe and continuing handicap to research on facial eczema has been the limited amount of dried toxic pasture available. To make the maximum use of this material, experiments were carried out using progressively smaller guinea pigs. Initially, animals in the weight range 200–300 g. were used[1]; subsequently, it was found that guinea pigs weighing 120–140 g. had a good chance of survival under the feeding conditions used in testing dried pasture samples and extracts. Below this weight range, mortality increased sharply. However, a procedure has since been developed for feeding extracts using two-day-old guinea pigs weighing 65–85 g. and these animals have proved satisfactory for routine use. As it has been found that the toxic dose needed to produce effects in young guinea pigs is roughly proportional to their bodyweight, these alterations have resulted in a large saving of toxic pasture.

The feeding techniques used at Ruakura for testing suspected toxic grass and extracts have been modified slightly over the four years that the guinea pig has been used for this purpose. These modifications have been mainly due to the use of smaller animals, and the procedures described below have been used unchanged for at least the last twelve months.

Feeding Procedure for Dried Pasture Samples

Pasture motor-mown from suitable areas under conditions when facial eczema seems likely is dried on a tray drier in an air draught at 95–105°C. obtained by drawing air through a coke furnace and a by-pass. The dried material is bagged and stored in a dry place until fed to guinea pigs.

For feeding, the dried grass is ground in a Wiley Mill to pass a 1 mm. screen and each daily portion of 25 or 30 g. is moistened with twice its weight of water immediately prior to feeding.

A guinea pig weighing 120–140 g. is taken from the colony in the afternoon and placed in an individual cage in the test room which is maintained between 65 and 75°F. Next morning, and subsequently, it receives a weighed amount of moistened dried grass in a detachable food container and a daily supplement of 10 g. green grass. Water is supplied *ad lib.* A daily record is kept of guinea pig bodyweight and weight of food eaten. After five weeks the animal is slaughtered and bled out. The liver is removed, weighed, and classified, as described earlier. Representative slices are cut from the lobes transverse to the direction of the bile ducts and fixed in formal-calcium. Sections prepared from them are stained using haematoxylin and eosin.

Grass found in this way to be toxic is chaffed and stored in sealed four-gallon tins in a refrigerator at about —10°C. Stored in this way, the toxicity has been found to be retained for more than a year without detectable loss.

Feeding Procedure for Grass Extracts

Non-toxic grass (N.T.G.) is cut and dried in large quantities during the winter and used as control or normal material. This dried grass is ground and is used both as an ingredient of the training diet and as a vehicle for dispersing extracts to be tested.

Guinea pigs about two to four days old and weighing 65 to 85 g. are placed in individual cages and offered a daily ration made by mixing 8 g. N.T.G., 4 g. full-cream powder, and 8 g. water, together with a supplement of 10 g. green grass and water *ad lib.* This training period continues until an animal is eating most of its ration, generally after three or four days, by which time it is slightly heavier than at the beginning.

The animal is then offered a test material, its daily ration being the same except that the N.T.G. is replaced by N.T.G. on which an extract to be tested has been dispersed. Sufficient extract is prepared for this diet to be maintained for three weeks.

For the fourth week, the diet is 10 g. N.T.G., 5 g. milk powder and 10 g. water. Bodyweight and food eaten are measured daily throughout. At the end of four weeks the animal is slaughtered and the liver treated as outlined above.

Experimental Results

In adopting these procedures, the following experimental results have been considered:

1. Even with the most toxic samples so far fed, visual examination of the liver fails to detect damage in less than ten days. From then on, proliferative changes begin to appear and increase rapidly with time. Similarly, hepatomegaly is seldom detectable after three weeks on toxic grass or extracts, is much more common after four weeks, and is even more pronounced after five weeks. Five weeks feeding for dried pasture samples was selected somewhat arbitrarily as a compromise between the needs for keeping the time for the test to

a minimum and for ensuring that as low a level of toxicity as possible can be detected.

2. At low levels reproducibility falls off; thus in an experiment where seven guinea pigs were fed the same amount of a slightly toxic dried grass sample for five weeks, five showed mild or moderate liver damage, one was classed as severe and one was considered normal. In some cases, apparently normal livers obtained in this way have been classified histologically as "abnormal, not definitely facial eczema". Subsequent chemical extraction of the pasture samples responsible and feeding of the extracts at several times the original level has produced mild or moderate facial-eczema lesions. It is considered, however, that such pastures are of too low a level of toxicity to be of practical use in systematic chemical fractionation.

3. In the extraction work, grass of known toxicity is used and, in general, information is sought as to which of several fractions contains the bulk of the liver-damaging substance and how much loss of toxicity has occurred in its preparation (E. P. White, pers. comm.) The quantity of toxic grass used per experiment is so adjusted as to produce severe liver lesions provided at least half of the toxicity is retained in one of the final fractions (E. P. White, pers. comm.).

   Detection of low levels of toxicity is less important and as a result the time per test can be reduced. Frequently, after three weeks feeding, the liver is examined with an otoscope through a small ventral mid-line incision. In this way there is a minimum of delay in deciding which extracts are toxic, but in all cases the guinea pigs are maintained for four weeks to ensure a more uniform basis for comparison.

4. At high levels of toxic dosage, the response in the guinea pig is highly reproducible. In more than thirty consecutive experiments the extracts fed had been prepared according to procedures subsequently found not to destroy toxicity; in all cases severe facial-eczema liver damage was produced.

   For economy of material the testing of grass extracts for the presence or absence of the liver-damaging substance required a procedure using the minimum amount of grass consistent with an unequivocal answer, and one test animal rather than a group. By using the dose levels indicated this becomes possible.

5. Initially all extracts were fed over a period of four weeks, followed by slaughter of the test animals. From a consideration of the time involved in the sequence: dosage, obstruction, proliferation, it was likely that the extract fed in the last week did not have time to produce any visible effect. This was confirmed when in the fourth week in a number of tests, replacement of the toxic extract by normal grass did not appear to give any less liver damage, although the total dose was diminished by one quarter. Response did fall off when dosage was maintained at the same rate for only two of the four weeks and little damage could be detected when only one week's dosage was used. Feeding the same total amount of the liver-damaging substance either for two or for three weeks produced serious liver damage consistently.

6. No visual liver damage has been detected in any guinea pig fed toxic material for one week and then immediately slaughtered. However, in a series of six guinea pigs fed the same toxic extract for one week followed by non-toxic diet for varying times, the results obtained were:

Period on Non-Toxic Diet	Visual Liver Damage
1 day	Nil
9 days	Moderate facial eczema
15 „	Moderately severe
21 „	Mild
21 „	Severe
29 „	Severe

Although this experiment indicated the progressive nature of the disease, the presence of mild damage in one of the animals after four weeks' feeding suggested that one week was probably not an adequate period over which to feed toxic extracts. Similarly, only one of four animals in which the total dose was administered over a three-day period subsequently developed severe lesions. It was, therefore, felt to be safer to feed extracts for a longer period and accordingly the present procedure was adopted.

7. The first toxic extract fed to a guinea pig was evaporated on to barley meal and force fed after moistening with water (E.P. White, pers. comm.). The remainder of the diet consisted of a normal guinea pig mash *ad lib.* supplemented with a small amount of green grass. Subsequently all extracts were evaporated on to dried non-toxic grass, and this material moistened with water made up the entire diet. Later a small amount of green grass was included as a daily supplement. This diet was found not to be adequate for very small guinea pigs which often would not eat enough of it to survive. Inclusion of the large supplement of milk powder now used resulted in a diet to which most young guinea pigs become very quickly adapted.

That such a range of feeds should not appreciably modify the toxicity of extracts suggests that the action of the liver-damaging material is substantially independent of the diet with which it is fed.

8. No facial-eczema liver lesions have ever been detected in guinea pigs fed non-toxic grass supplemented daily with 10 g. green grass. This non-toxic grass is collected during the winter since the disease, facial eczema, occurs in the field only during late summer and autumn.

9. An examination of a range of liver-function tests applied to affected guinea pigs failed to reveal any sufficiently marked differences. A very satisfactory and reliable procedure has, however, been

developed based on direct examination of the liver; its main disadvantage is the time required per test.

OTHER SPECIES AS TEST ANIMALS

An experiment was undertaken using toxic extracts evaporated on to the appropriate feeds to determine whether the rat, the mouse, or the chicken was comparable in sensitivity with the guinea pig.

Two bulk partly-purified toxic extracts were prepared by different procedures. Each was divided in the ratio 2:3:3:4 and evaporated on to diets for a mouse, rat, chicken, and guinea pig respectively, and fed using a three-weeks-plus-one procedure similar to the standard outlined above. The mouse and rat food was of the normal pellet type, the chicken food was crushed wheat, and the guinea pigs received dried grass plus milk powder. The rats and mice were one month old at the beginning of the experiment, the chickens one week old, and the guinea pigs about ten days old. When slaughtered, both guinea pigs showed moderately severe facial-eczema liver lesions, but all the other animals appeared to be normal histologically and to the naked eye.

It is concluded, at least where oral administration is used, that rats, mice, and chickens are not satisfactory test animals for work on facial eczema.

LIVER-FUNCTION TESTS

All blood samples used in these tests were obtained by heart puncture under ether anaesthesia but, when larger volumes were required for electrophoresis, stunning and partial decapitation was used.

Bilirubinaemia and Photosensitivity

Since in facial-eczema outbreaks sheep with affected livers frequently exhibit jaundice and phylloerythrinaemia, bilirubinaemia was regularly looked for in the guinea pigs being fed toxic grass and extracts. However, even where sufficient damage occurred to produce severely affected livers in four to five weeks, as described above, functional compensation apparently took place too rapidly for a positive Van den Bergh reaction to be given. Subsequently, two much-more-toxic grass samples were collected and in both cases direct feeding and extracts prepared from them have given positive V.d.B. tests, with levels up to 1.5 mg. bilirubin/100 ml. plasma. With the most toxic extract so far fed a positive test of 0.8 mg./100 ml. was obtained after only seven days.

In the latter case, the guinea pig was then fed green grass *ad lib.* for two days before being exposed during three periods totalling 1¾ hours to a beam of white light from two aircraft landing lights mounted six feet above with a fan placed near the animal to maintain normal temperature. This arrangement had previously been tested on control guinea pigs without producing any effects. The test animals evidenced increasing irritation by scratching its pink ears which became sensitive to touch. The reaction was typical of that obtained in guinea pigs photosensitized by injected dyes (N. T. Clare, pers. comm.). Later in the day it was killed because of its poor condition. Its subcutaneous tissues were bile stained although the liver did not show much obvious visible damage.

Another guinea pig, W135, diagnosed severe facial eczema by laparotomy, was grazed outdoors for a further eight weeks. At slaughter, the ears were extremely hard and leathery and one snapped when an endeavour was made to bend it. It is possible that this damage resulted from prolonged photosensitivity since it has also been observed in rats injected with phylloerythrin and in guinea pigs fed certain chlorophyll degradation products (N. T. Clare, pers. comm.).

Phylloerythrin occurs in the bile of normal, grass-fed guinea pigs from the Ruakura colony, but this pigment has not been sought in the blood of jaundiced animals described above owing to the minute quantities likely to be involved, especially as only a small amount of green grass is included in the diet.

Electrophoresis of Blood Proteins

Sera from four normal guinea pigs and five showing facial-eczema liver lesions ranging from mild to severe were examined electrophoretically by Dr. J. W. Lyttleton, Plant Chemistry Laboratory, Palmerston North. All test animals had been fed toxic material for four to six weeks.

Of the blood proteins examined, no change occurred in β- or γ-globulin concentrations, α-globulin increased slightly in the moderately and the severely affected animals and there was a slight drop in albumin in the severely affected animal. It is unlikely that these protein changes are sufficiently great for any of the liver function tests such as thymol turbidity and cephalin-cholesterol flocculation, which depend on them, to be of use in diagnosing facial-eczema liver damage in the guinea pig.

Hepatomegaly

Using results from 44 normal guinea pigs fed according to one or other of the standard feeding procedures, liver weight, y, was found to be related to the bodyweight, x, prior to slaughter, by the equation: $y = 1.4 + 0.033\ x$, the bodyweights ranging from 140 to 350 g. All results fitted this equation within $\pm$ 2 g.

All severely affected facial-eczema livers so far examined have exceeded this estimate, the greatest difference for a guinea pig fed five weeks being 27 g. (W125, bodyweight 234 g., liver weight found 36.2 g. predicted from equation 9.2 g.). Moderately affected livers also generally lie outside the normal weight range.

Bromsulphthalein Dye Clearance

Using lightly ether-anaesthetized guinea pigs, 0.3 ml. of 1% BSP sodium salt in 0.9% sodium chloride solution was injected intracardially and blood samples were withdrawn at approximately 1 min. and 3 min. into a syringe previously rinsed out with 10% potassium oxalate solution. The plasma was diluted tenfold with 1% sodium hydroxide solution and the optical density at 5800A was measured in a Beckman DU Spectrophotometer. The difference in log D, divided by the time in minutes between samples, was the first order velocity constant for clearance of BSP from the blood. For 24 normal guinea pigs k lay within the range 0.27 ± 0.13 min.$^{-1}$.

A guinea pig, showing severe facial-eczema liver damage when slaughtered after four weeks, was found one week previously to have

k = 0.22. Another guinea pig, W217, which also showed severe lesions was tested three days and one day before slaughter. On both occasions k = 0.11. As this liver showed a diffuse greenish staining due to bile pigment it is probable that the somewhat low value for k does indicate some impairment of excretion.

Alkaline Phosphatase

For 17 normal guinea pigs fasted overnight, blood alkaline phosphatase values ranged from 8.4 to 21.3 King and Armstrong units[3], with a mean of 13.7. For four guinea pigs bled immediately prior to slaughter at four weeks, when they showed severe facial-eczema liver lesions, values were 14.1, 25.8, 20.5, 26.7, with a mean of 21.8.

Blood Amino Acid Nitrogen

Using the method of Russell[4], a value of 6.15 ± 0.27 mg. AAN/100 ml. blood was obtained from ten normal guinea pigs fasted overnight. For the four severely affected guinea pigs referred to above, values were 4.7, 6.3, 7.9, 9.4 and for another severely affected animal examined prior to slaughter at six weeks the value was 5.9. Two of the values are significantly greater and one significantly less than normal.

Chemical Analysis of Guinea Pig Livers

Preliminary analyses on three normal, one moderate, one moderately severe, and one severe facial-eczema livers indicate that with increasing severity of liver damage there is a progressive reduction in dry-matter content and the dried liver has a lower nitrogen content. The differences are, however, slight in comparison with the observed liver-weight increase.

THE TERMINAL RESULT IN THE GUINEA PIG

The terminal result in guinea pigs with affected livers was studied by allowing three animals known or believed to be severely affected to continue on normal diets for longer periods. These were:

P399: Fed toxic grass for 20 days, then N.T.G. and green grass for 24 days. Animal grew normally for six weeks, then lost 20% of its bodyweight in three days and died. At death the liver was grossly enlarged, light in colour and weighed 28.3 g. (bodyweight 128 g.). Histologically it was essentially a mass of bile duct epithelial cells interlaced with fine fibrous tissue and containing numerous widely dispersed clumps of parenchymal cells.

P400: Fed toxic extract for 20 days, N.T.G. and green grass for 42 days. Normal growth for three weeks, then practically no further gain in weight. At death the liver was enlarged, light in colour, uniformly and grossly "flecked" and weighed 10.1 g. (bodyweight 120 g.). Histologically it resembled P399 except that very little parenchyma could be seen.

W135: Fed toxic extract for 20 days. Laparotomy then showed hepatomegaly and diffuse flecked appearance on several lobes. Classified as severe facial eczema. Maintained on N.T.G. and green grass for further 32 days. Laparotomy showed liver dark grey in colour with

light flecks. The blood vessels in the abdominal region were considerably dilated. After a further 24 days fed green grass and mash *ab lib.* the guinea pig was killed in poor condition. Over the first three weeks' feeding, bodyweight gain had been normal, then for several weeks the weight had remained more or less constant, and finally there had been a slow steady decline. Most of the liver was whitish-grey in colour, speckled with green. There was a fibrous cuff round the periphery of the liver, and nodules of regenerating tissue, more or less normal in colour and appearance, projected from the central part of the liver. The whole organ was considerably distorted and weighed 20.6 g. (bodyweight 201 g.). The ears were extremely hard and leathery. Urine was yellow and opaque, but the V.d.B. test was normal. Histologically the liver resembled P399 and P400 except that much more fibrous tissue was present; also in the nodules and the central part of the liver there was much apparently normal parenchyma, although this was being invaded by proliferating bile-duct epithelium.

Discussion

Subsequent to the observations reported by Evans, McFarlane, Reid, and Perrin[1], similar liver damage has been produced in guinea pigs fed more than 20 different dried grass samples. These samples were from four different areas—the Manutuke Research Station and the Makaraka Racecourse, both near Gisborne, the Claudelands Showground, Hamilton, and the Ruakura Animal Research Station. These samples were obtained over a period of five years during seasons when facial eczema occurred in sheep grazing these or nearby areas and strongly support the conclusion that the guinea pig is susceptible to the liver-damaging substance causing this disease.

The reproducibility of the liver damage produced by toxic extracts using the feeding procedure described earlier has considerably facilitated systematic chemical fractionation aimed at isolating the toxic material, while the reduction in the quantity needed per test has enabled much greater use to be made of the toxic grass available. It is unlikely that smaller test animals can be used since the rat, mouse, and chicken do not appear to be satisfactory and the lower limit of size of guinea pig has been reached; in many cases, guinea pigs are born too heavy to be used conveniently for testing extracts.

Experimental investigation of the primary facial-eczema liver lesion is more easily made in guinea pigs fed known levels of toxic grass for known times than in the grazing sheep and it is likely that a detailed study of the histopathology and biochemistry of this disease in the guinea pig will facilitate subsequent investigations with sheep.

The continuing liver damage observed in the guinea pig after cessation of feeding of toxic extracts is analogous to the field observation that liver damage frequently develops in sheep removed from suspected toxic pastures and placed on feeds known to be non-toxic.

The procedure adopted in testing dried grass samples and extracts differs from what normally happens in the field, where it is unlikely that the sheep is exposed to a constant level of toxicity for so long a period. The observed variability in response of guinea pigs fed toxic extracts for several days, followed by normal diets, suggests the possibility that

continued damage to the bile ducts may be required before the typical facial-eczema pattern is initiated.

The outward appearance of guinea pigs on test materials gives no indication of whether liver damage is occurring. Many guinea pigs found to have severely affected livers make good growth and appear to be in good health until the time of slaughter. It is likely that although the liver may increase to several times its normal weight functional compensation takes place sufficiently rapidly for no obvious effects to appear.

The small amount of grass required per guinea pig makes it feasible to test grass grown under controlled conditions in glasshouses. In this way, factors responsible for the occurrence of the facial-eczema liver-damaging substance in pasture could be studied. Similarly, by feeding to a guinea pig pasture cut and dried from a paddock at any known time, provided the toxicity is at least at the mild-to-moderate level, more precise information could be obtained as to when the liver-damaging substance occurs in grass. Correlation of such information with climatological data might improve the accuracy of prediction of toxic periods.

ACKNOWLEDGEMENTS

I should like to thank Mr. D. McFarlane, Gisborne Veterinary Club, for helpful discussion on the histopathology of facial eczema, and Mr. J. Kerr of the Diagnostic Section of this Station for preparing all liver sections.

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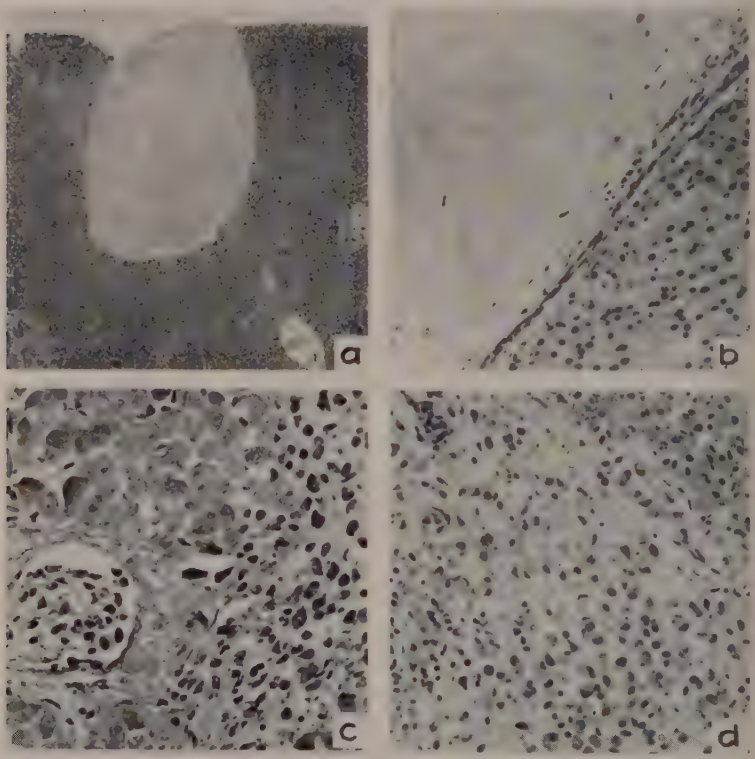
ADDENDUM TO

Photosensitivity Diseases in New Zealand

IX. The Susceptibility of the Guinea Pig to Facial Eczema *N.Z. J. Sci. Tech.* Vol. 38, pp. 491-6.

The following illustrations were inadvertently omitted when the above article was submitted for publication.

Fig. 1.—Sections of necrotic lesions in livers of guinea pigs fed toxic ryegrass. Haematoxylin and eosin staining.



Photos: A. L. Bryant.

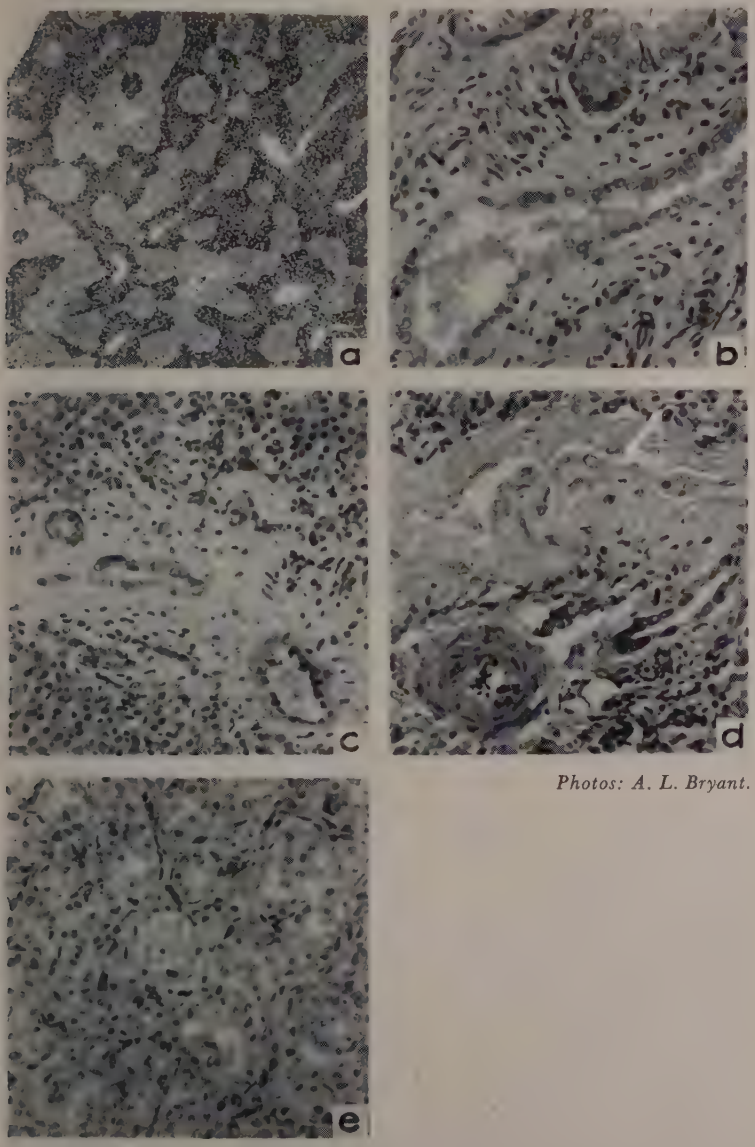
a. A large pale necrotic area involving several lobules, and clearly demarcated from the surrounding liver tissue which shows early ductule hyperplasia in the portal tracts. x 20.

b. Portion of the margin of the necrotic area shown in (a). x 200.

c. Margin of a necrotic area showing an early stage of resorption. Note persistence of cell outlines in the necrotic region. x 200.

d. Advanced stage in the resorption of a necrotic area. x 200.

Fig. 2.—Sections of biliary lesions in livers of guinea pigs fed for 50 days on toxic ryegrass. Haematoxylin and eosin staining.



Photos: A. L. Bryant.

a. Low-power field (x 20) showing numerous confluent and semi-confluent pale areas of ductule hyperplasia. Compare with Fig. 1a.

b. Longitudinal section of a moderate-sized bile duct showing epithelial degeneration, necrosis, and sloughing. Early periductal oedema and fibrosis are also present. x 200.

c. Transverse section of a moderate-sized duct showing almost complete loss of lumen together with advanced periductal fibrosis. x 200.

d. Complete disorganization and obstruction of a moderate-sized duct (arrow). Periductal fibrosis is marked. x 200.

e. An area of ductule hyperplasia. x 200.

THE INFLUENCE OF UNDERNUTRITION OF DAIRY COWS ON THE YIELD AND COMPOSITION OF MILK

By M. R. Patchell, The Dairy Research Institute (N.Z.), Palmerston North

(*Received for publication, 26 November 1956*)

Summary

The results of an experiment with monozygous twin cows on the effects of underfeeding for short periods both before and after calving are presented.

Milk yields were more severely depressed in cows that were underfed before as well as after calving than in those underfed only after calving. The solids-not-fat content of the milk was depressed by underfeeding, total-protein content and, apparently, lactose content being affected. The milk composition returned to normal quite rapidly after underfeeding ceased.

The group of cows underfed both before and after calving lost least body weight in early lactation and gained most during later lactation.

Introduction

This paper is a further report on a series of studies on the effect of short periods of undernutrition of dairy cows on the yield and composition of milk. Campbell and Flux (1948) and Flux (1950) reported on the effects of underfeeding of mature cows before calving, and Flux (1950) reported on a similar trial with two-year-old heifers. Flux and Patchell (1954) described a further experiment in which cows were underfed for a six-week period which commenced two weeks after calving. In the present paper the effects of underfeeding of cows both before and after calving on the yield of milk and on the solids-not-fat and total-protein contents are reported. The literature on the effects of underfeeding has been reviewed by Flux (1950) and Flux and Patchell (1954).

Experimental Method

Animals

The experiment was carried out during the 1952–53 dairying season with 12 sets of monozygous twins and during the 1953–54 dairying season with 15 sets of twins (see Table 1 for details of breed of cow, age at calving and calving dates). During the period of experimental feeding all cows were weighed twice each week, thereafter they were weighed once weekly. The weighings were made on a scale accurate to within 1 lb. The cows were milked twice daily.

Milk Weighing, Sampling, and Analysis

Milk yields were recorded at each milking for each cow. A two-day proportionate sample of milk from each cow was collected every week for analysis. Butterfat content was determined by the Gerber method, total solids by the evaporation method, and total protein by the Kjeldahl method.

Experimental Design

This was an incomplete balanced block type with three treatments, A, B, and C, as follows:—

TABLE 1. DETAILS OF ANIMALS USED
(Arranged in order of age at calving)

Season	Twin Pair Numbers	Breed	Age at Calving (years)	Days Between Calving Dates
1952–53	2–1	Grade Jersey	2	22
	14–13	Jersey × Friesian	2	12
	75–76	Jersey × Ayrshire	2	19
	94–93	Grade Jersey	2	6
	96–95	Grade Jersey	2	9
	97–98	Grade Jersey	2	17
	44–43	Grade Jersey	3	20
	25–26	Jersey × (Jersey × Shorthorn)	4	29
	71–72	Grade Jersey	4	21
	90–89	Grade Jersey	4	0
	17–18	Jersey × (Jersey × Poll Angus)	6	8
	53–54	Grade Jersey	6	20
1953–54	11–12	Grade Jersey	2	32
	39–40	Jersey × (Friesian × Ayrshire)	2	7
	99–100	Grade Jersey	2	14
	13–14	Jersey × Friesian	3	12
	67–68	Grade Jersey	3	3
	76–75	Grade Jersey	3	12
	85–86	Grade Jersey	3	21
	93–94	Grade Jersey	3	3
	95–96	Grade Jersey	3	10
	43–44	Grade Jersey	4	27
	25–26	Jersey × (Jersey × Shorthorn)	5	19
	49–50	Grade Jersey	5	10
	71–72	Grade Jersey	5	9
	89–90	Grade Jersey	5	16
	17–18	Jersey × (Jersey × Poll Angus)	7	17

A. Cows Well Fed Before and After Calving

During the whole pre-calving period the food consisted of good winter pasture, plus hay and silage *ad lib*. During October the cows were run on good pasture usually plentiful in supply, and supplemented in the late summer months with grass silage and chou moellier (marrow-stemmed kale).

B. Cows Well Fed Before Calving and Poorly Fed Immediately After Calving

The cows were with those in Group A and were fed similarly until calving. After calving they were underfed for six weeks, the area of pasture and weight of silage per cow being only 40% of those for cows in Group A. From six weeks after calving they were run with and were fed similarly to cows in Group A.

C. Cows Poorly Fed Both Before and After Calving

For 10 weeks before calving the cows were kept in a small bare field and fed 6 lb. hay and 4 lb. silage per cow per day. The object was

to cause them to lose body tissue reserves gradually as they approached calving. After calving the treatment was the same as Treatment B.

Results

Body Weight

The changes in the average weights of the cows in each treatment group are illustrated in Fig. 1 and 2. In order to show changes in body tissue reserves more clearly, the body weights of the cows were corrected individually for the increased weights of their gravid uteri. The data (unpublished) used for this correction were supplied by Dr. L. R. Wallace, of the Animal Research Station, Ruakura, from his records of the weights of gravid uteri of cows slaughtered at different stages of pregnancy. The average weight changes for the cows in each treatment group in late pregnancy and for different stages of lactation are shown in Table 2.

TABLE 2. Average Body-weight Changes (lb.)

Treatment Group	Year	10 Wks. preceding Calving*	After Calving		
			0-6 Wks.	6-12 Wks	6-36 Wks.
A	1	+ 23	— 32	+ 11	+ 38
	2	— 22	— 15	+ 8	+ 74
B	1	+ 14	— 9	+ 16	+ 97
	2	— 12	— 17	+ 42	+ 121
C	1	— 78	— 12	+ 72	+ 208
	2	—115	+ 11	+ 90	+ 199

* Calculated from body weights corrected for the weight of gravid uteri.

In the first year of the experiment the well-fed cows gained a little body weight in the ten weeks before calving and in the second it appears from the corrected body weights that they lost a little. In both years the cows in Group C lost weight, 78 lb. in the first year and 115 lb. in the second. During the first six weeks of lactation the weight changes varied between and within groups in different years, but the cows that were treated most severely (Group C) did not lose as much as did those that were well fed throughout (Group A). Thereafter the average body weights for all groups increased, the greatest gains being made by the cows in Group C, the smallest by those in Group A, with those of Group B cows intermediate.

Production

The treatment group means (adjusted for block differences, Cochran and Cox, 1950) together with the differences between adjusted means are shown in Table 3. Because of an error in the technique of taking milk samples from the special milk cylinders used, the butterfat percentages were unreliable and are not shown and the solids-not-fat and total-protein contents of the milk were calculated on a fat-free serum basis.

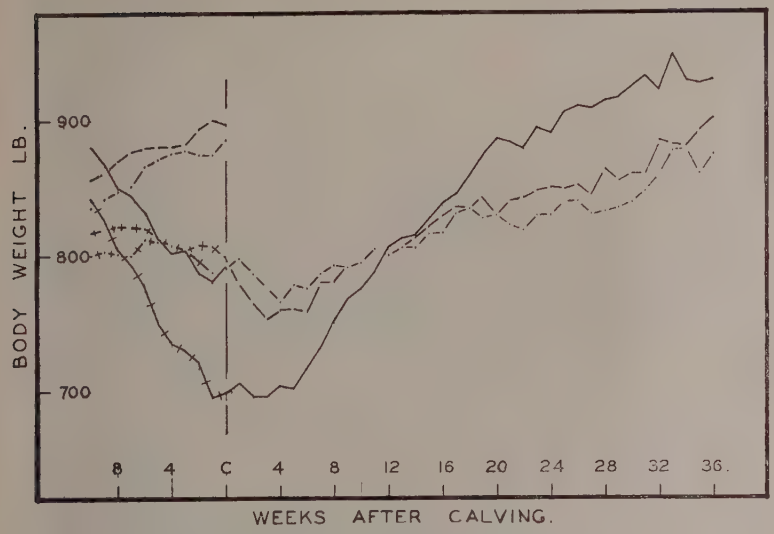


Fig. 1.—Average body-weight changes from 10 weeks before calving to 36 weeks after calving for the 1952–53 season
C denotes calving, Group A .—.—, Group B — — —, Group C ———— ——. The crossed lines (to the left of C) show the body-weights corrected for the weights of the gravid uteri. The uncrossed lines show the uncorrected body-weights.

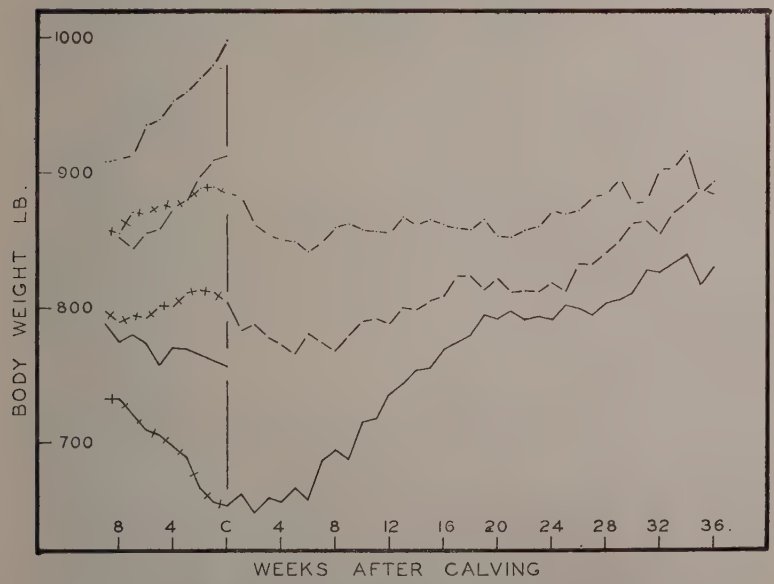


Fig. 2.—Average body-weight changes from 10 weeks before calving to 36 weeks after calving for the 1953–54 season.
C denotes calving, Group A .—.—, Group B — — —, Group C ———— ——. The crossed lines (to the left of C) show the body-weights corrected for the weights of the gravid uteri. The uncrossed lines show the uncorrected body-weights.

TABLE 3. MEAN LEVELS OF MILK CONSTITUENTS ADJUSTED FOR BLOCK EFFECTS

Treatment Group	0–6 Weeks			7–9 Weeks			252 Days		
	Average Weekly Milk Yield lb.	SNF %	Total Protein %	Average Weekly Milk Yield lb.	SNF %	Total Protein %	Total Milk Yield lb.	SNF %	Total Protein %
	1952–3								
A	202.4	9.41	3.37	202.1	9.21	3.35	5,626	9.53	3.56
B	180.6	9.33	3.51	192.9	9.30	3.41	5,571	9.66	3.59
C	152.1	9.16	3.29	179.4	9.28	3.40	4,972	9.55	3.56
Differences									
A–B	21.8	0.08	—0.14	9.2	—0.09	—0.06	55	0.13	0.03
A–C	50.3**	0.25*	0.08	22.8	0.07	0.05	654	0.02	0.00
B–C	28.5(*)	0.17	0.22	13.5	0.02	0.01	599	0.11	0.03
	1953–54								
A	195.1	9.66	3.59	202.0	9.54	3.45	5,971	9.70	3.67
B	164.7	9.41	3.44	195.4	9.29	3.41	5,474	9.45	3.57
C	149.1	9.06	3.29	171.2	9.33	3.45	4,634	9.35	3.58
Differences									
A–B	30.4*	0.25*	0.15(*)	6.6	0.25(*)	0.04	497*	0.25	0.10
A–C	46.0**	0.60**	0.30**	30.8*	0.21	0.00	1,337**	0.35*	0.09
B–C	15.6	0.35*	0.15(*)	24.2*	0.04	0.04	840**	0.10	0.01

Sig. diff. at 1% **
5% *
10% (*)

The effects of the underfeeding treatments were more severe in the second year of the experiment than in the first. This was probably a result of increased pugging of pasture in the second spring, which was much wetter than the first. Although the area per cow grazed was the same in each year more feed was wasted and consequently the levels of feeding for all cows were lower than for the corresponding group in the previous year.

In both years the cows that were underfed after calving (Groups B and C) produced, as might be expected, less milk in the first six weeks of lactation than those in the control group. The effect was more severe in the case of Group C cows, which were underfed before calving as well The differences between the cows in Groups A and B were smaller and not statistically significant in the first three weeks of subsequent normal feeding, while the cows in group C did not catch up so soon, significant differences still existing between the averages in the first three weeks of normal feeding.

The composition of the milk was altered by the underfeeding, the effects being more pronounced in the 1953–54 trial. In the first year the solids-not-fat content of the milk of the cows in group C was reduced during the underfeeding, but the difference was statistically significant

only for the comparison between Group A and Group C. Apparently the difference in the total-protein content explained only a small part of the difference in solids-not-fat. During the first three weeks of subsequent normal feeding the differences in milk composition were small and not statistically significant.

In the second year, 1953–54, the solids-not-fat content of the milk of the underfed cows was considerably reduced, the effect being greatest in the cows in Group C. Only about half of the fall in the solids-not-fat content was caused by a fall in the total protein content of the milk, although the differences in this factor were particularly large and clear cut in the comparison Group A versus Group C. The differences were greatly reduced in the first three weeks of normal feeding, and those in total-protein percentage had almost disappeared.

The differences between the group mean solids-not-fat contents 1953–54 were examined weekly after underfeeding ceased, to see how rapidly milk composition returned to normal. In the last week of underfeeding the difference between Groups A and B was 0.16%, and between B and C 0.17%. By the next week they were approximately half as great, and a week later both were about 0.04%. Thereafter the small differences disappeared slowly over about six weeks.

Milk yields of cows in all groups were about the same in the last few weeks of lactation in the 1952–53 season, but in the next year, although the cows in group B caught up to those in Group A after about three months lactation, those of group C lagged behind through the whole lactation. In neither year did the total-protein content of the milk of the cows in the different groups differ appreciably after the first two months of lactation, but in 1953–54 the cows in group C showed a lower solids-not-fat percentage for the last twenty weeks of lactation. This was presumably caused by lower lactose percentage, a "drying off" type of change associated with lowered milk yield.

The results for 252-day lactation periods, in the last columns of Table 3, show differences between the group means which were partly due to the immediate effects of the treatments and partly due to their effects on later lactation. It is clear that the underfeeding before and in early lactation reduced milk yields for the whole lactation and also appeared to reduce the solids-not-fat content of the milk in 1953–54.

DISCUSSION

The results of this experiment showed that whereas underfeeding immediately after calving depressed milk yield and the solids-not-fat content of the milk, underfeeding in this period following underfeeding before calving had a much more severe effect. Recovery in milk yield after underfeeding subsequent to calving was quite rapid, but when underfeeding started before calving, milk yield was adversely affected over the whole of the lactation.

The underfeeding lowered the protein content of the milk, but also must have reduced levels of some other solids-not-fat constituent, presumably lactose. The results for the second year suggest that, after the underfeeding ceased, recovery of the total protein content of the milk was more rapid than that of the other constituent affected.

In the 1953–54 experiment the reduction in the solids-not-fat content of the milk of the cows in Group B was of the same order as that observed by Flux and Patchell (1954) in an experiment involving underfeeding for a period of six weeks commencing two weeks after calving.

The body-weight changes of the cows during lactation were of considerable interest. Despite being underfed during the first part of lactation, the cows in Group B lost no more body weight (in one year less) than the control cows in Group A, and subsequently gained body weight more rapidly. The cows in Group C lost on the average somewhat less body weight than those in the other groups during the first six weeks of lactation, and thereafter gained very rapidly. It is apparent from these results that attempts to make cows contribute body reserves to lactation should be directed to feeding sufficiently well before and after calving to ensure establishment of full lactation.

From the point of view of the manufacturer of milk products, the effects of underfeeding early in lactation on milk composition are of considerable interest because lowered solids-not-fat content of milk obviously results in lowered yield of cheese or milk powders per unit volume of milk.

Under New Zealand farming conditions, where most cows are mated to calve some weeks before the rapid growth of pasture in the spring months brings adequate food supplies, it seems likely that in normal years the milk composition of many cows is affected in the same way as that of the cows in Group B in the present experiments. Years of poor winter and spring feed supplies probably produce changes in milk yield and composition more like these shown for the cows in group C, pronounced while underfeeding lasts, reduced when adequate feeding begins, but in many cases showing depressed milk yields and adversely affected milk composition throughout lactation.

Acknowledgements

The author wishes to acknowledge the work of the staff of The Dairy Research Institute (N.Z.), Chemistry Laboratory, under Dr. F. H. McDowall, who carried out the milk analysis; of Mr. D. Collis who carried out the sampling of the milks and the computational work; of the Institute farm staff, under Mr. A. Goodman, who milked and looked after the animals; and thanks Professor W. Riddet, for his interest in the experiment.

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